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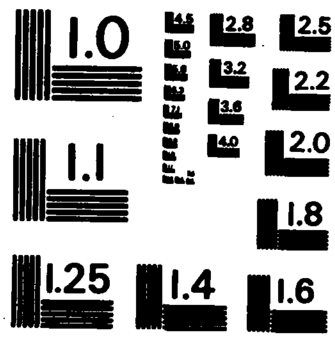

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STATISTICAL ANALYSIS OF NEAR-SURFACE SOIL COMPRESSIBILITY DATA FROM RALSTON VALLEY, NEVADA

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1 November 1981

Technical Report

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A statistical analysis of geotechnical data from Ralston Valley, Nevada, is conducted with the objective of seeking relationships whereby near-surface-soil compressibility may be predicted within acceptable limits. Such relationships can be utilized in place of much of the extensive and costly boring, core sampling, and laboratory analysis that is required for design of such strategic structures as those for the MX Missile System. Possible predictors of compressibility which are investigated include site descriptors obtainable from maps, seismic surveys, bag samples from borings, and undisturbed core samples. Study findings suggest that site characteristics from maps, particle gradation variance, and soil porosity offer promise as predictors of compressibility at depths of ten feet.

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SUMMARY

Site Characterization represents an important part of the Air Forces's effort in MX missile siting. Decisions about MX design parameters relating to survivability and hardness require estimates of subsurface soil properties, particularly compressibility. Such information is usually available only after a lengthy and detailed program of boring and testing undisturbed core samples has been completed. This report illustrates the use of modern statistical analysis to estimate subsurface soil compressibility, thus permitting substantial cost reductions in the site characterization effort.

The objective of the analysis is to investigate a number of geographical, geologic, and engineering variables which characterize a site, and to establish which among these will provide useful predictions of subsurface compressibility. An extensive geotechnical data base for Ralston Valley, Nevada, has been assembled as a result of subsurface exploration and laboratory testing by the U.S. Army Engineer Waterways Experiment Station. This somewhat unique set of data provides a basis for statistical analysis and modeling, seeking relationships by which compressibility may be estimated, using other, more easily measured site characteristics. The analysis emphasized compressibility at a depth of ten feet.

A first observation before addressing such data is that if compressibility is relatively homogeneous throughout a valley, prediction at any potential site is greatly simplified. The Ralston Valley data, however, showed that near-surface compressibility varies greatly among sites and borings scattered throughout the valley. Accordingly, information about individual sites must be taken into consideration.

It is possible to describe a potential missile site in terms of information obtained from a map, using slope, elevation, surficial soil type, and so on. Using a composite of these map variables, it was found that the sites on the valley floor, with the predominant surficial soil type found there, had significantly different stress-strain relationships than sites above the valley floor having a different surficial soil type. Accordingly, a result of the statistical approach employed is that prediction of near-surface compressibility appears to be substantially improved by consideration of a site's location and surficial soil type. For example, mean compressibility at a four megapascal uniaxial loading was found in the data to be 3.83 for sites on the valley floor with surficial soil type 5Y, and 4.69 for higher sites with soil type 5I. Thus it appears that we can improve our ability to estimate near-surface compressibility by simply taking into account site characteristics from a map.

Bag samples removed from borings provide gradation information about subsurface soils. From the Ralston Valley data it was found that measures reflecting the dispersion of particle size showed promise as predictors of compressibility. Measures locating the gradation curve (reflecting particle size), on the other hand, appear to have little connection with compressibility. For sites on the valley floor, a useful predictor of compressibility was found to be specimen porosity, with the property that the greater the stress, the better the prediction of strain. As can be seen, the effects of site location were found to be pervasive in the Ralston Valley data.

In addition to sampling via borings, an extensive program of seismic surveys had been completed in Ralston Valley. However, data that was examined from this seismic work proved to be unrelated to the compressibility data from ten-foot depths.

These findings were obtained from a somewhat methodical first look at the Ralston Valley data, and pertain only to uniaxial strain compression at depths of ten feet. Nevertheless, it is believed that the statistical analyses reported here contribute to our understanding of subsurface soils in valleys such as Ralston Valley, and accordingly may help reduce the cost and effort of site characterization for MX missile siting.

TABLE OF CONTENTS

TABLE OF CONTENTS (CONTINUED)

LIST OF ILLUSTRATIONS

LIST OF TABLES

LIST OF TABLES (CONTINUED)

SECTION 1

INTRODUCTION

Information about geologic and material properties at candidate sites is a necessary input to the Air Force site selection process for the MX missile system. Soil characteristics may significantly influence system design parameters relating to vulnerability and hardness. Acquisition of soil property data exclusively through laboratory tests of core samples from borings is probably not feasible, if a moderate to large number of sites are considered. On the other hand, laboratory testing of bag samples or undisturbed core samples offers levels of accuracy which are generally not available with other current methods.

It would be advantageous if some of the soil property values which are sought could be predicted at desired levels of accuracy from easily measured geologic and material characteristics of the sites, so that sampling, involving costly boring and laboratory testing of undisturbed core samples, could possibly assume more of a confirmation role in a site characterization effort. In particular, predictive relationships linking near-surface compressibility to other site characteristics could greatly reduce the time, effort, and consequential cost to assess and characterize a potential site.

This report describes the results of a variety of analyses seeking such relationships. The approach employed is that of statistical analysis and data-based modeling, primarily employing linear and non-linear regression analysis in an interactive mode. The data base was furnished by the Structures Laboratory of the U.S. Army Engineer Waterways Experiment Station, and was the product of an extensive program of collecting and testing samples from Ralston Valley, Nevada.

Although we shall present a number of results which are of interest in their own right, our emphasis shall be on the prediction of near-surface compressibility. <u>Compressibility</u> as used here refers to the uniaxial strain obtained at various stress or load values for an undisturbed core sample from a ten-foot depth. Primary attention will be given to E4, the strain which occurs at a loading compression stress of 4.0 megapascals.

The Data Base

During the period 1979-1981 considerable effort was expended on the collection of soil samples and other data from Ralston Valley, Nevada, and on laboratory testing and analysis of the samples. The data collection plan[1] called for sixteen sites in the valley to be investigated through seismic testing together with removal of bag soil samples and undisturbed core samples from borings. Sampling work was completed in 1980 and by mid-1981, results of the seismic work[2,3,4] and the laboratory tests on soil samples[5,6,7] had been completed. Most importantly, all of this information was assembled in a comprehensive information storage and retrieval system at the U.S. Army Engineer Waterways Experiment Station[8].

A subset of this vast amount of data, dealing with general site characteristics and compressibility at ten-foot depths, was extracted and used for the statistical analysis reported here.

The first statistical effort was to ignore specific site differences and treat the Ralston Valley data as one large sample. Results of this initial work are given in Section 2 of this report, together with consideration of statistical modeling concerns with independence and normality in dependent random variables.

Compressibility was the primary dependent variable in the analysis, and in seeking to estimate or predict compressibility, all other measures were treated as independent variables. Of these, seismic and soil measures were necessarily considered to be stochastic.

Classes of Independent Variables

Independent variables (as potential predictors) were classified according to the cost or effort required to obtain values for them, and each class was investigated separately. Classes of independent variables were, in order of increasing cost, map variables, seismic measures, bag-sample measures, and undisturbed-sample measures.

Map Variables are those site properties for which values may be obtained from a FUGRO map of the valley under consideration. Results of analyses to determine if these variables could be used as predictors of near-surface compressibility are given in Section 3 of this report.

Seismic measures are those available from a seismic survey done at the site, and results of analyses pertaining to these variables (compression-wave velocity and surface layer thickness) are given in Section 4.

Bag Sample measures provide information on soil gradation, and results of studies seeking relationships between gradation measures and near-surface compressibility are given in Section 5.

Undisturbed-Sample measures are among the most costly to evaluate in the data base, since samples must be carefully removed from the boring, protected, and transported to the laboratory for testing. This is, of course, part of the procedure necessary to actually measure compressibility, but at this point it is still possible to measure the porosity of the specimen without the added cost and effort of uniaxial strain tests. Accordingly, statistical analysis was undertaken seeking a relationship between compressibility and porosity, with results presented in Section 6 of this report.

The report ends with a discussion of the conclusions from these analyses. Selected numerical details are furnished in the Appendix.

SECTION 2

GENERAL MEASURES FROM THE RALSTON VALLEY DATA BASE

Our first results from work with the data from Ralston Valley examine what can be said about porosity (PRSTY), dry density (DDEN), and compressibility at loads of 2.0, 4.0, and 6.0 megapascals (E2, E4, and E6) by treating the data as one large sample without regard to other information we have about the sites. We shall also comment on normality and independence of individual observations.

General Estimation of Soil Measures

Subsequent sections will discuss ways in which site characteristics, seismic data, and gradation information can assist in improving estimates of compressibility in MX valley soils. As a starting place, however, it is useful to see how well one might do in estimating without using information from maps, bag samples, and so on. Accordingly, in this section we shall ignore other information that we have and treat the data as being simply from fifty-eight borings in Ralston Valley. From this, we shall attempt to make general statements about near-surface compressibility in the valley. A list of the fifty-eight borings from which data is used is given in the Appendix to this report, Table 23.

Treating the data as a random sample from the valley as a whole, values of standard statistical estimators were computed for E2, E4, E6, PRSTY, and DDEN at a depth of essentially 10 feet. These are displayed in Table 1.

TABLE 1. Estimated means for E2, E4, E6, PRSTY, and DDEN at 10' depths in Ralston Valley. (n=58)

Estimated mean value of E2	2.70
95% confidence interval, mean E2	2.41 - - 2.95
Estimated mean value of E4	3.94
95% confidence interval, mean E4	3.56 - - 4.33
Estimated mean value of E6	4.92
95% confidence interval, mean E6	4.46 - - 5.37
Estimated mean porosity	0.355
95% confidence interval, mean PRSTY	0.345 - - 0.366
Estimated mean dry density	1.70
95% confidence interval, DDEN	1.68 - - 1.73

The statements in Table 1 refer only to average values for the valley as a whole. Our sample of size 58 is ample to provide fairly good confidence limits on these average values, but our ability to forecast compressibility at a particular site in the valley will depend upon variance.

Table 2 shows medians and sample variance for the various measures. If we wished to forecast E4 at a 10' depth at a particular site in the valley, the goodness of our forecast

TABLE 2. Medians and Sample Variances for E2, E4, E6, PRSTY, and DDEN at 10' depths. (n=58)

Measure	Median	Variance
E2	2.70	1.12
E4	4.07	2.16
E6	5.20	3.12
PRSTY	0.348	0.0016
DDEN	1.72	0.0098

would be reflected by its variance; it is the purpose of examining site characteristics to reduce this variability.

On the basis of these 58 borings, we would forecast that if undisturbed samples were taken at 10' depths in Ralston Valley, measured values of E2, E4, E6, PRSTY, or DDEN would fall within the 95% limits shown in Table 3.

TABLE 3. 95% Limits for Individual Values of E2, E4, E6, PRSTY, or DDEN.

Measure	Forecasted 95% Intervals
E2	0.93 - - - 5.04
E4	1.47 - - - 7.22
E6	1.66 - - - 9.55
PRSTY	0.277 - - - 0.433
DDEN	1.51 - - - 1.90

The forecasting performance reflected by the values in Table 3 is a direct consequence of the standard deviation values shown in Table 2, which include variability caused by surficial soil types and site locations, soil gradation differences, and inherent soil heterogeneity together with the variability that is added during the process of gathering and testing soil specimens. Variance due to the latter source is of unknown magnitude, but represents a lower bound on residual variances obtainable when we try to reduce variability using information about site and soils.

Some caution should be exercised in interpreting the values shown in these three tables. What we properly have here is multivariate data from fifty-eight soil specimens, and it is well known that E2, E4, and E6 are highly correlated, as are PRSTY and DDEN. Accordingly, the intervals shown for these measures are related. The 95% intervals shown are for E2 <u>or</u> E4 <u>or</u> E6.

Spatial Clustering

Thus far we assumed that the fifty-eight borings were scattered randomly through the valley. Actually, it is sixteen sites that are scattered through the valley, although we know that the sites were not chosen in a truly random manner.

What is of interest here is that the borings are clustered at each site, so that we have two, three, or four pieces of information at each site. The sites are physically distant from one another, while the borings at a site are not.

An important consideration when undertaking a data study of this kind is the independence of the individual observations, and in this regard, it is useful to have some assurance that data from adjacent borings may be considered independent. Site RA5Y was one of the two sites in Ralston Valley where extensive boring was done, and the boring plan at this site provided one set of borings at 62.5' spacings, and another (but not mutually exclusive) set at 7.8' spacings. One measure of spatial independence is a small correlation between adjacent borings: in this case one would hope that observations taken at equally spaced positions in a line are not correlated with next neighbors. Sample correlation coefficients for various measures from the two boring sets at Site RA5Y are shown in Table 4. Samples are small here, and a significant sample correlation coefficient would in this case be of the order of 0.5. Clearly, there is little to suggest problems due to spatial effects.

TABLE 4. Correlations between Adjacent Borings at Site RA5Y.

Variable	62.5' Spacing (n=15)	7.8' Spacing (n=14)
E4	0.08	0.15
DDEN	0.05	0.11
PRSTY	-0.38	-0.11

Normality in Compressibility

Many of the data-based modeling procedures which will be used laterin this report assume a normally-distributed dependent variable. While in most cases these procedures are somewhat robust in coping with moderate non-normality[9,10], it is useful to take a closer look at our dependent variable in this regard. Strain is computed as the ratio of deflection to original specimen size. As such, we have here a random variable clearly bounded on the unit interval, but not a random variable of Bernoulli trial origins.

Discussions with engineers at Waterways Experiment Station indicated that specimens undergoing uniaxial strain tests will be essentially the same initial size, so that one may view strain not unreasonably as the product of a single random variable and a constant, rather than as the ratio of two random variables. The bulk of the density will be at the lower end of the unit interval, and one might therefore expect moderate positive skewness. This was investigated descriptively using stemleaf plots, and the skewness noted was modest.

Transformations provide one well-known statistical tool for reducing skewness. Much of the statistical work with the Ralston Valley compressibility data was done twice: with, and without transformations. Since results never differed appreciably, only the untransformed versions will be presented here.

Conclusions

In this section we have treated the data as simply a single sample from the valley, without regard for site differences within the valley. This first look at the Ralston Valley data provides a larger sample to work with than we will encounter later. On the other hand, it is clear that the variance of compressibility is large under this approach; it is now the task to see how much of this variance can be accounted for by known site and specimen characteristics. In the next section we will look at easily obtained information from maps, to see if knowledge of these factors will reduce our variance in estimating compressibility.

SECTION 3

MAP VARIABLES AS PREDICTORS OF NEAR-SURFACE COMPRESSIBILITY

Maps, such as those available from FUGRO, offer a variety of information relating to the physical characteristics of potential sites. Because this information may be obtained more easily than that requiring seismic surveys or boring efforts, it is of particular interest to attempt to determine if there are relationships between near-surface compressibility and site characterizing information available from FUGRO maps.

As measures of near-surface compressibility we shall use E2, E4, and E6, denoting the uniaxial strain at loading stresses of 2, 4, and 6 megapascals, respectively. However, since these three measures are so highly correlated, the results for E4 will usually suffice. As elsewhere in this report, results pertain to depths of ten feet.

Using data from fifty-one borings at fourteen sites in Ralston Valley, we seek relationships between near-surface compressibility and the following map variables:

1. ELEV: the site's elevation, in meters;
2. SLOPE: the surface slope at the site;
3. EAC: the site's elevation above the valley floor, meters;
4. DCV: the site's distance from the valley center, km;
5. DFM: the site's distance from the mountains, km;
6. DEP: the site's distance from the edge of the playa, km;
7. the surficial soil type at the site, 5Y, 5I, or U.

In statistical analysis, two or more factors are said to be confounded if the data is such that it is not possible to test for the individual effects of the factors. This was the case among many of the map variables in the Ralston Valley data set.

This section first describes the confounding problem and its resolution, and reports statistical work exploring the effects of site type on E4. Then, within each site type, we may look for effects of previously confounded variables on E4. In all of this, data from fourteen of the sixteen sites in Ralston Valley is used: data for the remaining two sites is reserved to test any predictive relationships found.

Confounding of Surficial Soil Type with Other Variables

Among the fourteen sites in Ralston Valley from which data was used, nine sites have been identified as having Type 5Y surficial soil, four sites as having Type 5I surficial soil, and one site as having Type U soil. This corrected classification is substantially different from the one upon which the data collection effort was based, where sites were distributed among four surficial soil types.

We wish to look first at surficial soil type as a basis for forecasting E4, but unfortunately in this data, surficial soil type is confounded with four other independent variables: EAC, SLOPE, DFM, and ELEV. In Figure 1, the top scale locates the fourteen sites in terms of EAC, their elevations above the center of the valley. It is easily

Y denotes a site with surficial soil type 5Y.
U denotes the site with surficial soil type U.
I1, I2, I3, and I4 denote the four sites with surficial soil type 5I.

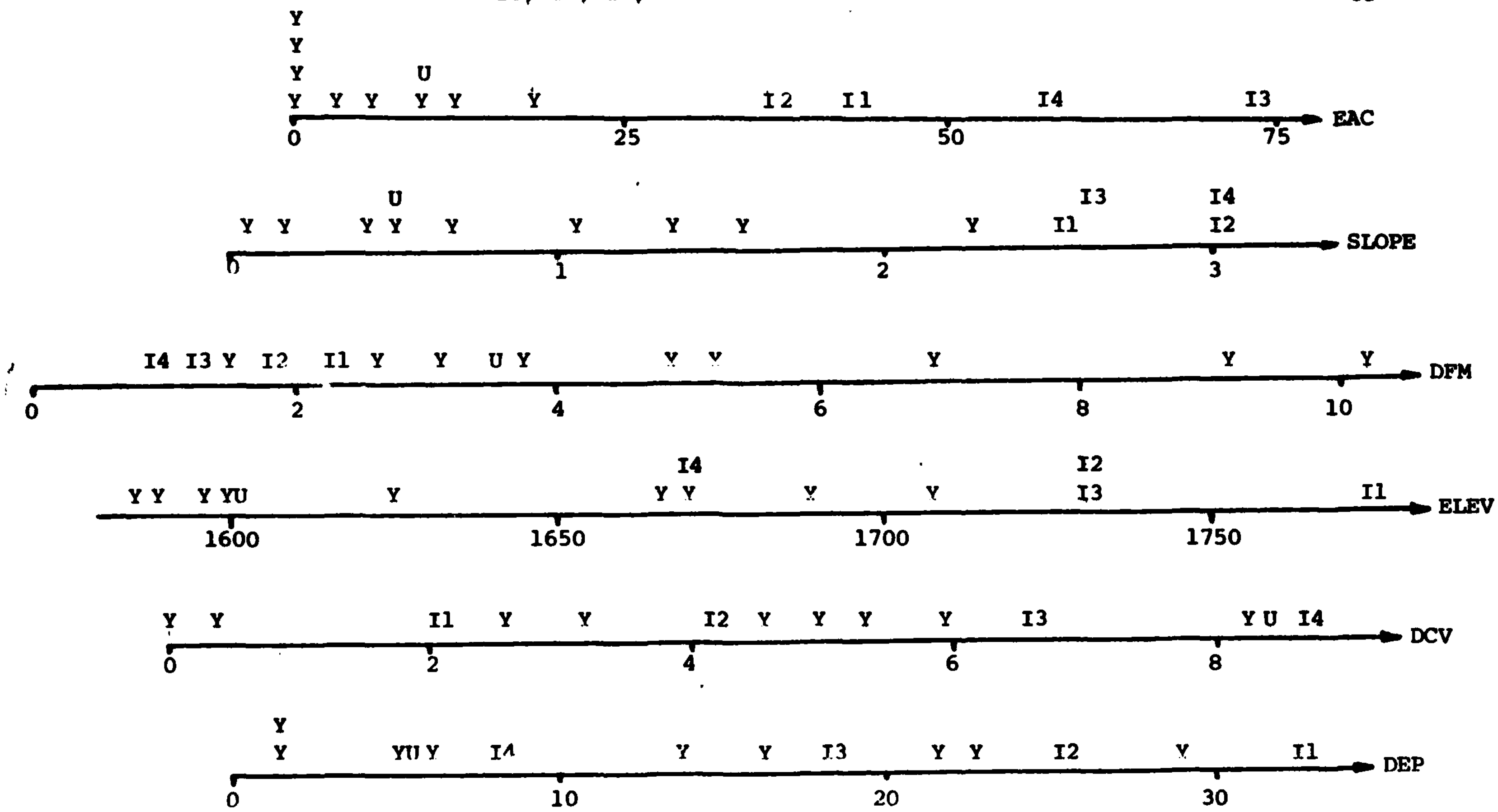

FIGURE 1. Site Characteristics by Surficial Soil Type.

seen that the 5Y and U sites are all on or near the floor of the valley, whereas the sites with surficial soil type 5I are not. Accordingly, we are unable to separate surficial soil type and EAC in terms of their effects on compressibility.

Similar confounding with surficial soil type may be observed in Figure 1 on the second scale, SLOPE. The distance from the mountains DFM is also confounded with soil type, as shown by the third scale in Figure 1. Finally, it is clear from the fourth scale that one would have difficulty determining whether an effect on E4 was really due to soil type, or to the elevation at the site. Accordingly, we have four of the site variables confounded with surficial soil type in the sense that for statistical analyses, we cannot separate them from surficial soil type.

Site Classification

Because of the confounding of surficial soil with four of the site variables we are considering, it will not be possible to make a general statement about any relationship between soil type and near-surface compressibility, independently of these site variables. What can be done, however, is to classify the Ralston Valley sites on the basis of surficial soil type and other factors, and then check to see if site types differ in E4. The site classification scheme is shown in Table 1. (The data for each type of site is given in the Appendix.)

TABLE 5. Classification of Sites

	SITE CLASSIFICATION		
	Type I	Type II	Type III
Surficial Soil	5Y	5I	U
EAC, meters	0 - 20	35 - 75	9
SLOPE, %	0 - 2.5	2.5 - 3.0	0.5
DFM, km	1.5 - 10.5	0 - 2.5	3.6
ELEV, meters	1580 - 1710	1670 - 1780	1600
# sites	9	4	1
# borings	34	13	4

From Table 5 we see that Type I sites are on or near the floor of the valley, on relatively flat land away from the mountains, with surficial soil type 5Y. Type II sites are on higher, more sloping ground with surficial soil type 5I, and are closer to the mountains than Type I sites. The Type III site is primarily distinguished from Type I sites because the surficial soil is U, rather than 5Y.

Effects of Site Classification on Near-Surface Compressibility

The first factor we shall investigate in terms of impacting values of E4 is site classification, as described in the preceding section.

Analysis of variance showed that among the three site types, mean E4 differed significantly at the 0.01 level. (The

TABLE 6. Sample Statistics for Compressibility Measures, Site Classification Groups

Classification	# Borings	Measure	Mean	Variance	Std. Dev.	Median
		IE2	2.58	1.26	1.12	2.56
		IE4	3.83	2.62	1.62	3.84
Type I Sites	34	IE6	4.80	3.83	1.96	4.74
		IE4-IE2	1.24	0.34	0.58	1.18
		IE6-IE4	0.97	0.17	0.41	0.96
		IIE2	3.16	0.59	0.77	2.95
		IIE4	4.69	0.72	0.85	4.28
Type II Sites	13	IIE6	5.86	0.76	0.87	5.61
		IIE4-IIE2	1.54	0.05	0.23	1.60
		IIE6-IIE4	1.16	0.03	0.18	1.16
		IIIE2	1.32	0.08	0.29	1.25
		IIIE4	1.97	0.11	0.33	1.94
Type III Site	4	IIIE6	2.50	0.12	0.35	2.50
		IIIE4-IIIE2	0.65	0.01	0.08	0.65
		IIIE6-IIIE4	0.53	0.002	0.045	0.53

same is true for E2, E6, E4-E2, and E6-E4. Since these measures correlate so highly with E4, we will simply emphasize E4 in this analysis.) Sample means and other measures are given in Table 6. Variances of E4 differ significantly among the site types. Among pairs of means, mean IE4 is significantly different from mean IIE4 at the 0.05 level, and significantly different from mean IIIE4 at the 0.001 level (Aspin-Welch tests).

We may also compute 95% confidence intervals for mean values of E4; these are displayed in Table 7.

TABLE 7. Ninety-Five Percent Confidence Intervals for Mean E4

At Type I sites:	3.26 - - 4.40
At Type II sites:	4.19 - - 5.20
At Type III sites:	1.44 - - 2.50

Effects of DCV and DEP on Near-Surface Compressibility

Two site characteristics which were not confounded with soil type in this data are site's distance from the center of the valley, DCV, and the distance from the edge of the playa, DEP. Confounding problems between these two variables are not as evident as in the case of surficial soils. As shown in Figure 2, there is a distinct confounding for the Type II sites, and for all sites (with the exception of one, RC4U) those nearer the playa tend to be further from the center of the valley. This may be partly due to the shape of Ralston Valley at its

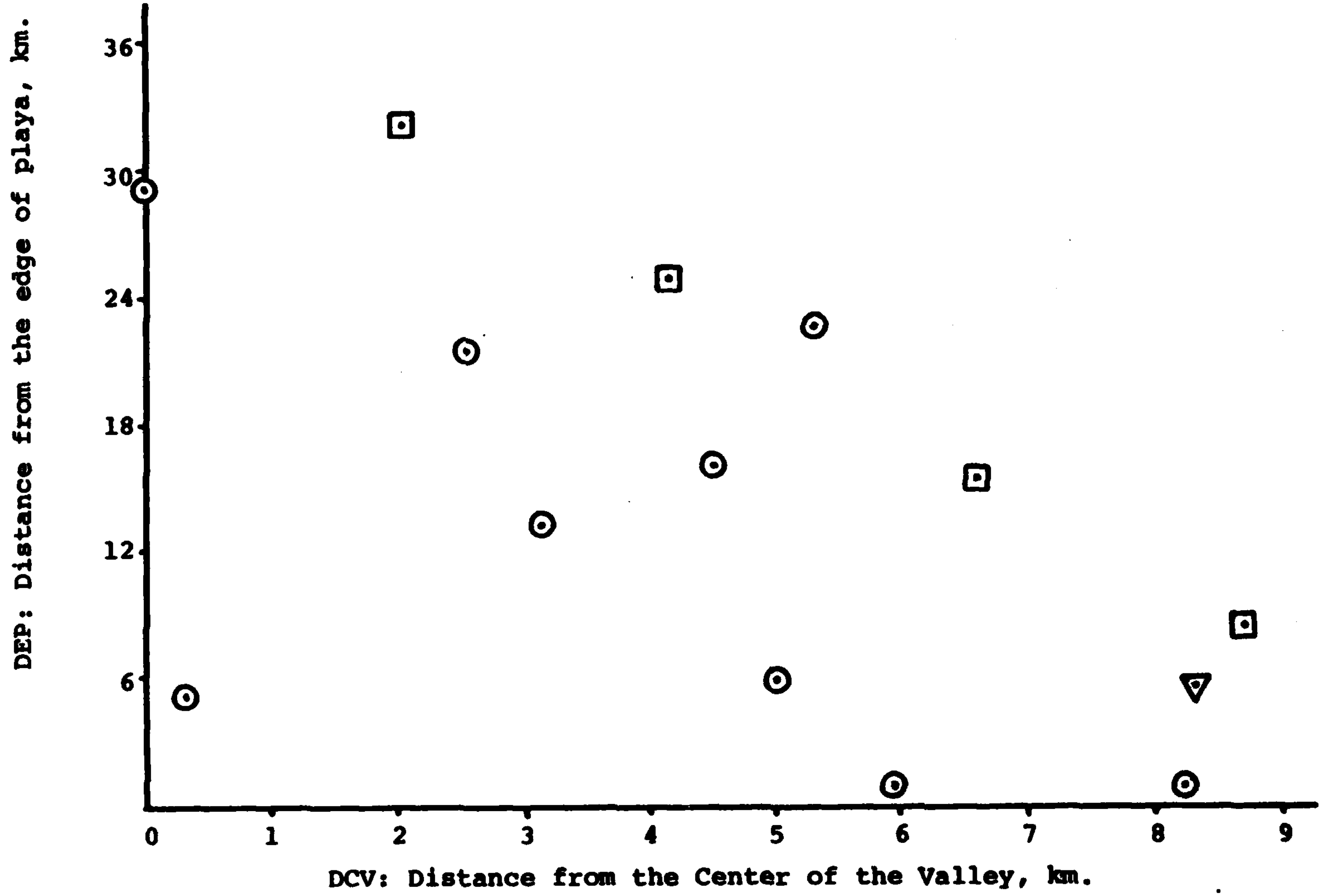

FIGURE 2. DCV vs DEP for Four-teen Sites in Ralston Valley

- ⊙ Type I Sites
- ⊡ Type II Sites
- ▽ Type III Site

Southern end. We shall examine DCV and DEP separately, and for now, independently of site type.

Investigated independently of other site characteristics, neither DCV nor DEP appear to have a significant effect on near-surface compressibility; coefficient of determination values of 0.006 and 0.088 were obtained.

Effects of Site Characteristics Within Site Types

It is useful to look at the effects of such site characteristics as ELEV and SLOPE as they vary within a site classification. Such an analysis, however, is hampered by several factors. First, in each analysis we will be able to explore only a limited range of values for the characteristics of interest. Second, the results of the analysis must be qualified by site classification. Third, we may find further confounding of some characteristics within site type. Finally, sample size drops substantially. We will not be able to say anything about the Type III site since there is only one, and even at Type II sites, relationships must be based on four sites, meaning only four values for each independent variable.

Among the nine Type I sites, ELEV and DEP are clearly confounded, as shown in Figure 3. Also, since these sites are all close to the valley floor, there isn't much difference among them in terms of EAC. If we do pay attention to EAC, we find that among Type I sites, it is confounded with SLOPE, as shown in Figure 4. Thus within the Type I sites we have

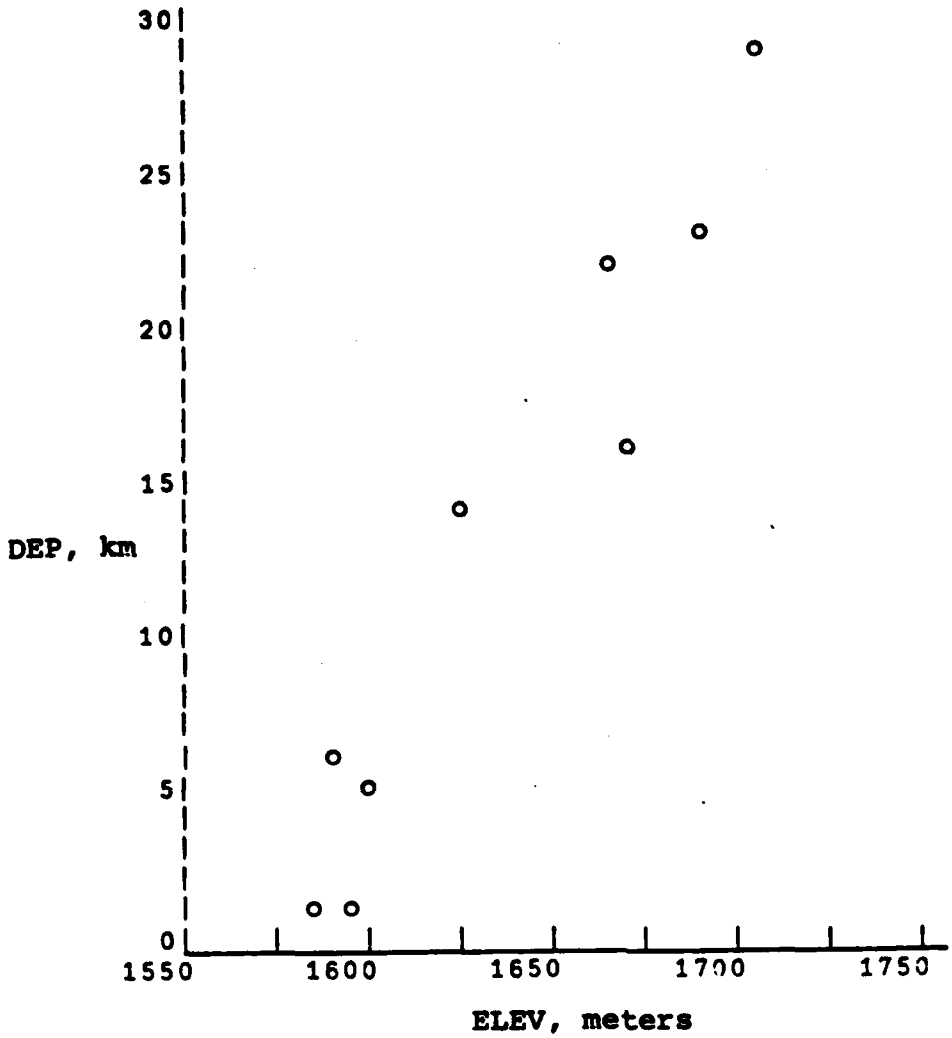

FIGURE 3. Plot of ELEV vs DEP for Type I Sites

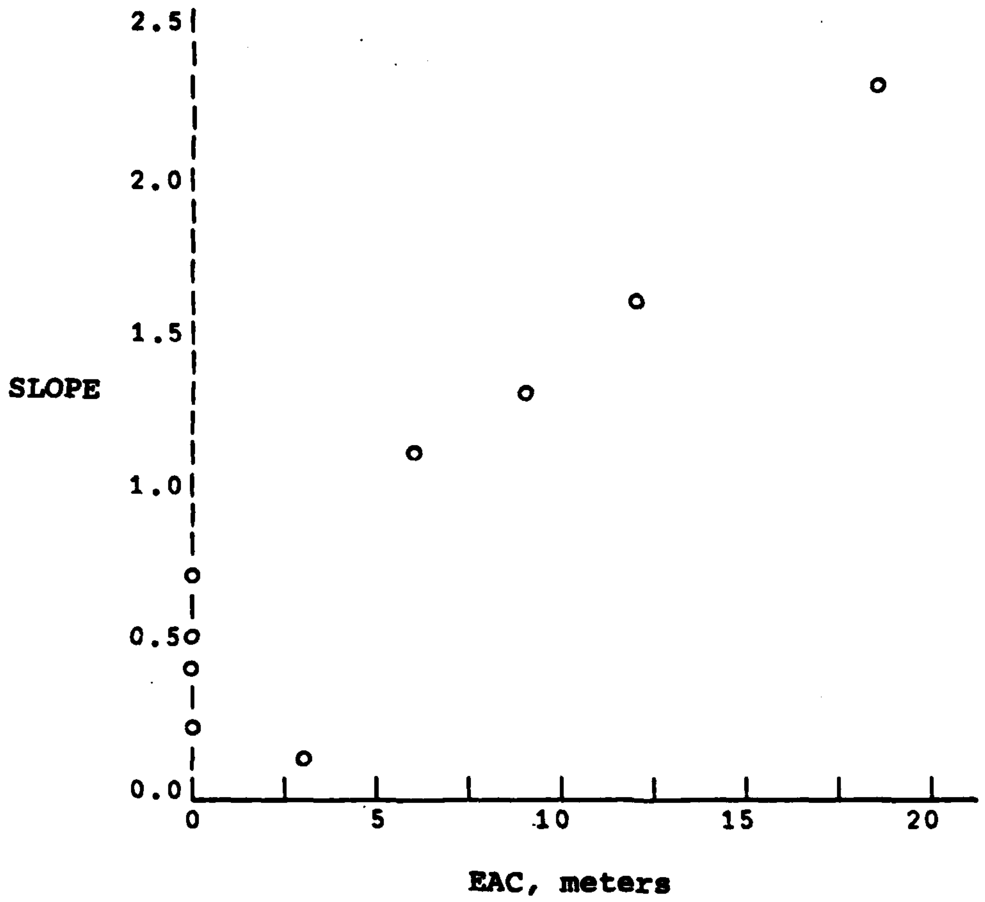

FIGURE 4. Plot of EAC vs SLOPE for Type I Sites

available just four variables:

1. EAC or SLOPE
2. ELEV or DEP
3. DFM
4. DCV .

Tentative exploration of the effects or influence of these variables on E4 within Type I sites shows that none of these factors has a significant effect on E4.

Among the four Type II sites, the ground slopes are all about the same, as are the distances from the mountains. This was shown in Figure 1, where it also is evident that ELEV, DFM, DEP, and DCV are all confounded for Type II sites. Accordingly, among Type II sites we are able to explore the effects on E4 of essentially two independent variables:

1. ELEV or DEP or DFM or DCV
2. EAC.

Exploratory regression analysis failed to show signs that these factors might be useful as predictors of E4 at Type II sites. Here, as in previous work, residuals were inspected (without success) for signs that nonlinear analysis would be appropriate.

The Type III site, RDU, has been previously shown to have significantly smaller values for near-surface compressibility than Type I sites. One interesting comparison is afforded by comparing this site to a similar Type I site, so that differences found could be attributed to surficial soil.

Site RCU, classified as Type I, is similar to Site RDU as shown in Table 8 below. Although sample mean values for E4

TABLE 8. Characteristics of Sites RDU and RCU

	Site RDU	Site RCU
Surficial Soil Type	U	5Y
EAC, meters	9	0
SLOPE, %	0.5	0.43
DFM, km	3.6	3.75
ELEV, meters	1620	1585
DEP, km	5.5	1.2
DCV, km	8.4	6.0
Mean E4	1.97	3.21
Variance of E4	0.11	2.48
# borings	4	4

appear quite different, sample sizes here are too small to permit statistical confirmation. (The Aspin-Welch t-statistic for E4 means is -1.54 with 3.26 degrees of freedom.)

Conclusions

1. We are unable to show from this data that E4 at ten-foot depths is influenced by the site's distance from the center of the valley, or by its distance from the edge of the playa.

2. Type I sites (on or near the floor of the valley, on relatively flat land with surficial soil Type 5Y) have a significantly smaller but more variable value of E4 than Type II sites (on higher, more sloping ground, closer to the mountains with surficial soil Type 5I.)

3. A Type III site (different from the general characteristics of Type I sites in that the surficial soil is Type U) has significantly smaller and less variable values of E4 than Type I or Type II sites.

4. Within site types, we were unable to show from this data that any of the following variables had any effect on E4:

Site elevation
Site elevation above valley center
Slope at site
Distance from the mountains.

However, because of confounding with other site characteristics, we cannot give from this data a general result about the effects of these factors on E4.

5. All results cited above also hold for E2 and E6.

6. Computed 95% confidence intervals on mean compressibility measures are given below:

	Mean E2	Mean E4	Mean E6
Type I Sites	2.19 - 2.97	3.26 - 4.40	4.11 - 5.49
Type II Sites	2.69 - 3.63	4.19 - 5.20	5.33 - 6.39
Type III Sites	0.86 - 1.78	1.44 - 2.50	1.94 - 3.06

The next section will give the results of analyses looking at the use of data from seismic surveys to forecast near-surface compressibility.

SECTION 4

COMPRESSION WAVE VELOCITY AND SURFACE LAYER THICKNESS AS PREDICTORS OF NEAR-SURFACE COMPRESSIBILITY

Seismic testing provides information about a site that includes estimates of the depths of material layer boundries and estimates of compression wave velocity in the material, as a function of depth. During planning for the Ralston Valley effort, seismic surveys were considered to offer promise as a way to predict near-surface compressibility, in that it was hoped that seismic measures and compressibility would be related, at least in a statistical sense.

In the data set used in the analysis reported here, measures from seismic survey lines at fifty-one borings in Ralston Valley were employed. In most cases these survey lines passed within one foot of the center of the boring. Additional seismic work at two sites, RBU and RB5Y, had included three lines which were oriented to be 60° apart, in a spoked wheel configuration. Analysis of variance studies of the seismic data from these lines was undertaken to see if the seismic results for a point varied due to the compass orientation of the survey line, and no significant effects were found.

General Results

Values of three seismic measures were used:

CPSURF: The compression wave velocity in the surface layer, mps.

CP10: The compression wave velocity at a depth of ten feet, mps.

ZBOT: The thickness of the surface layer, meters.

The first three columns in Table 9 show overall means and standard deviations for the three seismic measures.

TABLE 9. General Results for Seismic Results from 51 Borings.

	CPSURF	CP10	ZBOT
Sample Mean	372.1	711.9	1.18
Std. Dev.	56.0	134.6	0.54

TABLE 10. Correlation Coefficients among Seismic Measures and E4.

	CP10	ZBOT	E4
CPSURF	0.26	0.28	-0.09
CP10	1.00	0.38	0.01
ZBOT	0.28	1.00	-0.08

From the right-hand column in Table 10 we can see that the sample correlation values between E4 and the three seismic measures are so small as to be essentially negligible. This implication that, in general, the values from seismic surveys have effectively no connection with E4, was supported by inspection of scatter plots and multiple linear and nonlinear regression attempts. (The latter yield, for example, coefficient of determination values of 0.012 for a linear function and 0.014 for a power function.)

Effects of Seismic Measures Within Site Types

It was pointed out in a previous section that site variables could be handled for statistical purposes by classifying sites in Ralston Valley, and it was found that E4 varied significantly among Type I, Type II, and Type III sites. Accordingly, it is of interest to see if seismic measures vary among site types, and more importantly, to see if we might find relationships between compressibility and these measures, within site types.

Means and standard deviations for seismic measures within site types are shown in Table 11 together with E4 values for comparison. Analysis of variance results show CP10 values to differ significantly (5%) among site types; values of CPSURF and ZBOT do not. One may also note from the

TABLE 11. Means and Standard Deviations for Seismic Measures Within Site Types.

Site Type	n		CPSURF	CP10	ZBOT	E4
I	34	$\bar{x}$	368.9	698.3	1.08	3.83
		s	32.9	115.4	0.47	1.62
II	13	$\bar{x}$	383.1	782.7	1.26	4.69
		s	98.4	166.3	0.64	0.84
III	4	$\bar{x}$	363.5	597.25	1.75	1.91
		s	29.1	59.0	0.44	0.33

table that sample means for CP10 agree in ranking with those for E4.

Conclusions

In view of the high hopes that seismic measures would be related to near-surface compressibility, these statistical results must be termed very disappointing. Despite lengthy analysis using linear and nonlinear regression, none of the three seismic measures investigated (CPSURF, CP10, and ZBOT) showed any evidence of being related to near surface compressibility.

In the next section we will devote attention to data from bag samples of material taken from borings as possible predictors of compressibility.

SECTION 5

SOIL GRADATION AND NEAR-SURFACE COMPRESSIBILITY

Bag samples of material removed from borings at various depths provide an estimate of the frequency distribution of particle size in the material. The subject of this section of this report is the analysis of such gradation data from Ralston Valley, and its relationship to compressibility E4 at ten-foot depths.

Gradation Measures

This work used gradation data from bag samples from approximately ten-foot depths at 51 borings in Ralston Valley. Two primary measures we used:

D10 - - the 10th percentile sieve size, and

D50 - - the median sieve size.

Additionally, three candidate measures of dispersion were explored as single predictors of compressibility:

D50 - D10,

D10/D50, and

D50/D10 .

Also examined were the Burmister parameters computed from the sample gradation curves:

LCR - - the parameter related to the slope of the gradation curve, and

CRD100 - - the parameter locating the gradation curve, and

CRD100/LCR.

Table 12 shows sample correlation coefficient values for these measures together with sample means and standard deviations. The sample correlation coefficient value of 1.0 is due to rounding, but tells us that D50-D10 is repeating the information provided by D50. The is probably because D10 is very small relative to D50. The correlation values of 0.98 between CRD100 and CRD100/LCR is probably due to the comparatively small standard deviation of LCR. From this, we shall drop D50-D10 and CRD100/LCR from further consideration and concentrate on the remaining measures.

Relationships Between Gradation Measures and Near-Surface Compressibility

Our basic measure of near-surface compressibility will continue to be E4. Earlier work showed that E2, E4, E6, DELE4 = E4-E2, and DELE6 = E6-E4 we all highly correlated in a collective sense. These measures all correlate to about the same extent with D10/D50, with values -0.35, -0.37, -0.38, -0.36, and -0.34.

In the right-hand column of Table 13 we see sample correlation coefficient values between compressibility E4 and six candidate gradation measures. The ratio D10/D50

TABLE 12. Sample Correlation Coefficients Among Gradation Measures, n=51.

	D10	D50	D50 -D10	D10/D50	D50/D10	CRD100	LCR	CRD100/LCR
D10	1.00	0.46	0.40	0.50	-0.29	0.54	0.05	0.58
D50		1.00	1.00	-0.05	0.19	0.74	0.14	0.84
D50-D10			1.00	-0.09	0.22	0.72	0.14	0.82
D10/D50				1.00	-0.49	0.00	-0.31	0.01
D50/D10					1.00	0.09	0.08	0.09
CRD100						1.00	0.59	0.98
LCR							1.00	0.50
Means	0.06	1.15	1.09	0.06	48.04	24.01	5.45	3.90
Std. Dev.	0.12	1.51	1.46	0.07	55.77	29.46	1.15	4.39
Medians	0.02	0.54	0.49	0.03	30.50	11.78	5.60	2.26

TABLE 13. Sample Correlation Coefficients Between Gradation Measures and E4.

	D10	D50	D10/D50	D50/D10	CRD100	LCR	E4
D10	1.00	0.46	0.50	-0.29	0.54	0.05	-0.04
D50		1.00	-0.05	0.19	0.74	0.14	0.16
D10/D50			1.00	-0.49	0.00	-0.31	-0.37
D50/D10				1.00	0.09	0.08	0.33
CRD100					1.00	0.59	0.09
LCR						1.00	0.18

and its reciprocal show promise as single predictors of E4, and we shall explore both of them before choosing one or the other.

Although the sample correlation coefficient values of -0.37 and 0.33 are, with 51 observations, substantial enough to capture our attention, scatter plots of D10/D50 vs E4 (Figure 6) and D50/D10 vs E4 (Figure 5) are not particularly encouraging as to the worth of this measure in predicting E4. Treated individually, these plots suggest that relations other than linear should be explored. An example is given in Figure 7 by the scatter plot of $(D10/D50)^{0.5}$ vs E4.

Using regression analysis, a number of functional relationships between E4 and D10/D50 and between E4 and D50/D10 were explored. For functional forms where it made a difference whether one used the independent variable or its reciprocal, D10/D50 was superior as an independent variable. Remaining candidate functions are listed in Table 14, together with a summary of statistical performance from nonlinear regression analysis.

With proper parameters, each of the functions listed in Table 14 would serve as a basis for relating mean E4 to D10/D50, as indicated by the significance levels on the F statistics. On the other hand, none of the functions offer a truly substantial reduction in variability, as indicated by the values for the coefficients of determination. Also, standard errors, where comparable, show little difference.

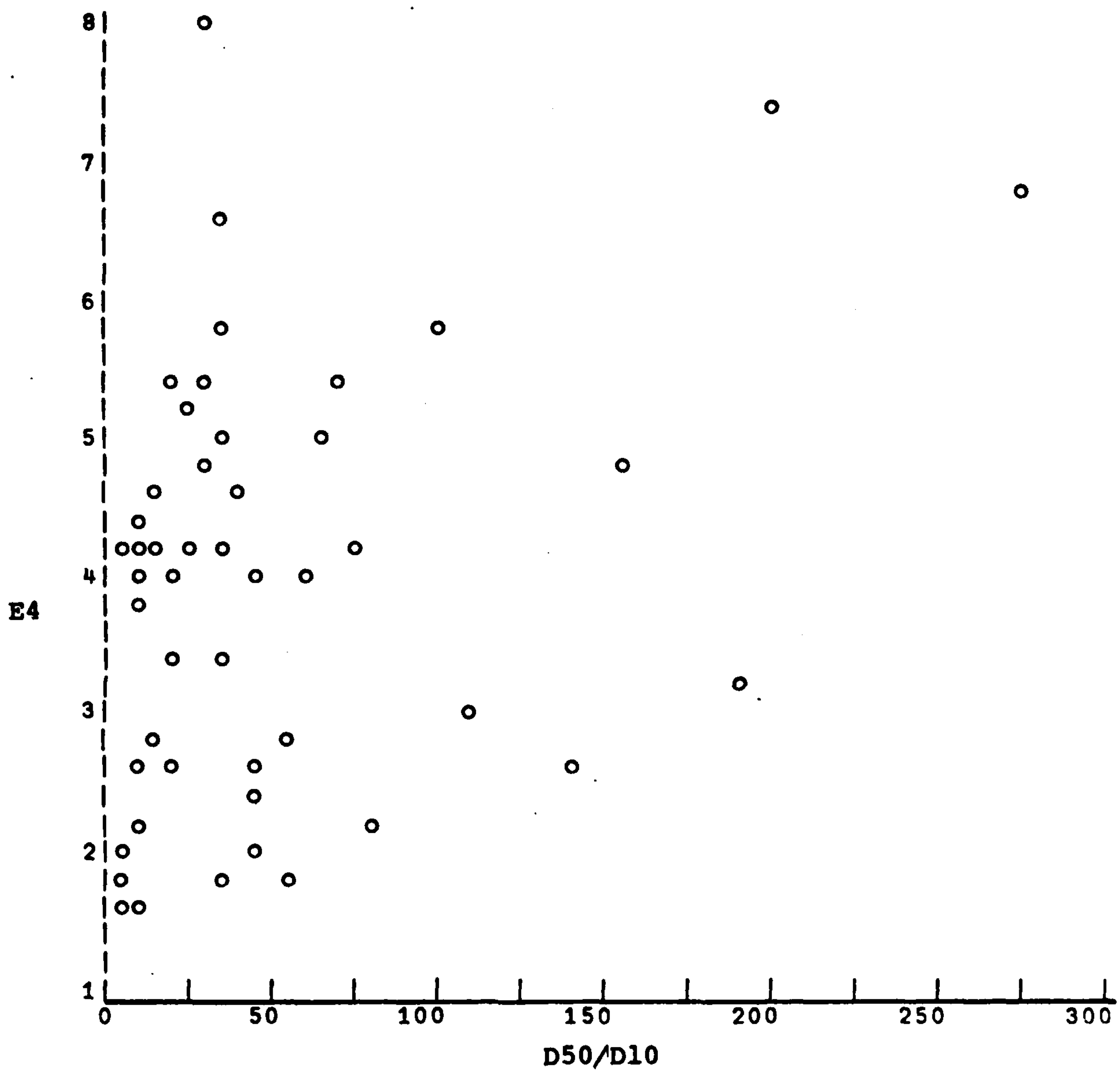

FIGURE 5. Scatter Plot of
E4 vs D50/D10

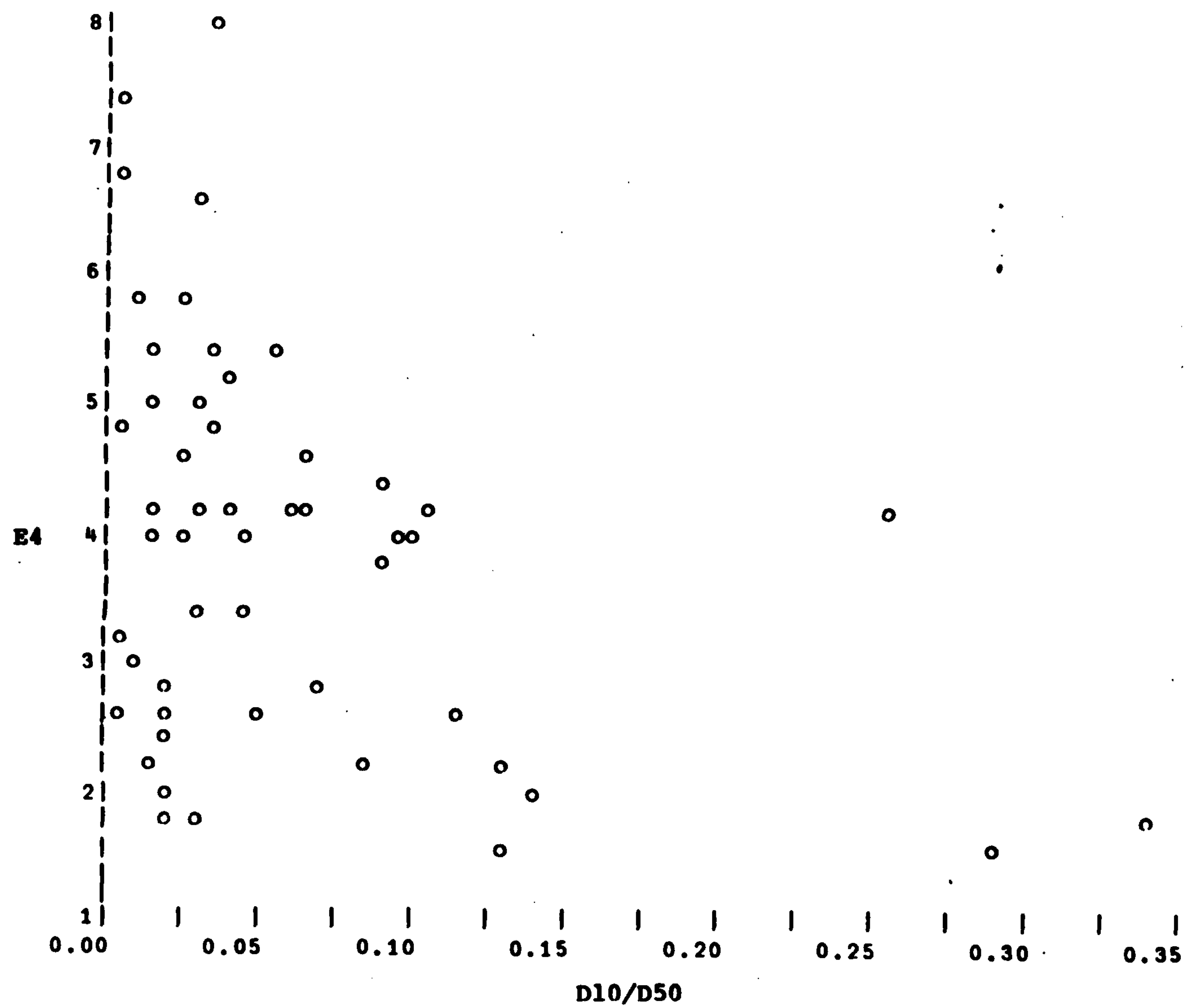

FIGURE 6. Scatter Plot of E4 vs D10/D50

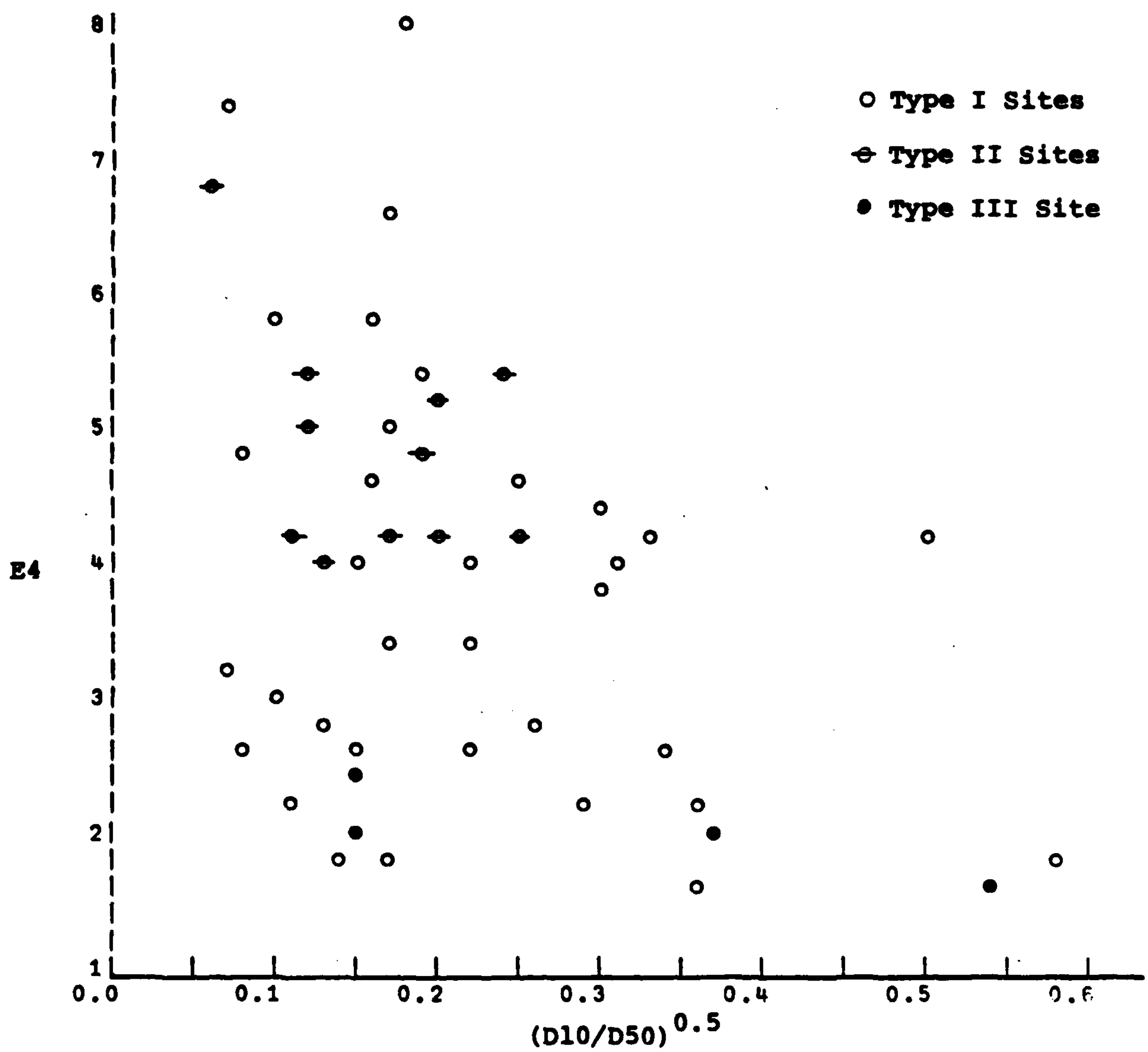

FIGURE 7. Scatter Plot of E4 vs $(D10/D50)^{0.5}$

TABLE 14. Statistical Results from Linear and Nonlinear Regression Analysis.

Values marked (*) are comparable only to each other.

Values marked (**) are not comparable to other standard error values shown.

Function, where y = mean E4	F	d.f.	Signif Level	Coeff. of Determ.	Standard Error
Linear:					
$y=a+b(\bar{D}10/D50)$	7.68	1,49	1%	0.136	1.447
Product:					
$y=a(D10/D50)^{b}$	7.27	1,49	1%	0.129	0.393*
Reciprocal:					
$y=a+b(D10/D50)^{-1}$	5.80	1,49	2.5%	0.106	1.472
Square Root:					
$y=a+b(D10/D50)^{0.5}$	8.05	1,49	1%	0.141	1.442
Quadratic:					
$y=(a+b(D10/D50))^{2}$	8.76	1,49	0.5%	0.152	0.356**
Semilog:					
$y=a+b\ln(D10/D50)$	7.323	1,49	1%	0.130	1.452
Exponential:					
$y=\exp(a+b(D10/D50))$	9.91	1,49	0.5%	0.168	0.384*
Cubic:					
$y=a+b(D10/D50)+c(D10/D50)^{2}+d(D10/D50)^{3}$	2.582	3,47	10%	0.141	1.472

If one proposed to use D10/D50 as a predictor of E4, three possible functions selected from Table 14 might be the linear form (for simplicity), the exponential form (because it looks best in this group), and the quadratic form (because it is second best). From the regression analysis the three possible prediction equations for mean E4 would be

$$E4 = 4.3863 - 8.1276(D10/D50) \quad ,$$

$$E4 = \exp(1.4264 - 2.45(D10/D50)) \quad ,$$

and

$$E4 = (2.0672 - 2.1884(D10/D50))^2 \quad .$$

Ninety-five percent confidence limits for mean E4 may be approximated by

$$4.3863 - 8.1276(D10/D50) \pm (2.013)(1.447)\sqrt{g(D10/D50}$$

for the linear form,

$$\exp\left(1.4264 - 2.45(D10/D50) \pm (2.013)(0.384)\sqrt{g(D10/D50)}\right)$$

for the exponential form, and

$$\left(2.0672 - 2.1882(D10/D50) \pm (@.013)(0.356)\sqrt{g(D10/D50)}\right)^2$$

for the quadratic form, where

$$g(D10/D50) = 1/51 + ((D10/D50) - 0.05942)^2/0.24345 \ .$$

Examples of mean E4 forecasting using the ratio D10/D50 are given in Table 15 together with results ignoring D10/D50. Here, three cases (identified by quartiles of D10/D50) are examined and for each case, point estimates of mean E4 and 95% confidence limits are given.

TABLE 15. Examples of Forecasting Mean E4 Using D10/D50.

	Case 1	Case 2	Case 3
D10/D50	0.0177	0.0328	0.0834
A. Forecast ignoring D10/D50:			
Point Estimate	3.90	3.90	3.90
95% Conf. Int.	3.47 - 4.34	3.47 - 4.34	3.47 - 4.34
B. Forecast using the linear form:			
Point Estimate	4.24	4.12	3.71
95% Conf. Int.	3.77 - 4.72	3.68 - 4.56	3.28 - 4.14
C. Forecast using exponential form:			
Point Estimate	3.99	3.84	3.39
95% Conf. Int.	3.51 - 4.52	3.42 - 4.31	3.03 - 3.81
D. Forecast using quadratic form:			
Point Estimate	4.12	3.98	3.55
95% Conf. Int.	3.65 - 4.60	3.56 - 4.42	3.16 - 3.96

Forecasting E4 Using D10/D50 and Other Measures

Now that we have D10/D50 as a single predictor of mean E4, it is of interest to go back over other gradation, seismic, and site measures to see if they will as an added dimension improve forecasting performance by D10/D50. Using multiple regression analysis the following were explored:

1. D10 and D10/D50
2. D50 and "
3. LCR and "
4. CRD100 and "
5. ZBOT and "
6. CP10 and "
7. DCV and "
8. DEP and "
8. CPSURF and " .

With one exception, this work produced no substantially improved statistical results over forecasting E4 by D10/D50 using the exponential form. Adding variables, of course, always reduces degrees of freedom while making the fit appear better via the coefficient of determination. The one result worthy of note is

$$E4 = \exp(a + b(D10/D50) + cD10) \quad .$$

This function furnished a coefficient of determination of 0.226, and was significant at the 0.005 level with 2 and 48 degrees of freedom. Coefficients were a = 1.1415, b = -3.286, and c = 0.975.

<u>Effects of Gradation Measures Within Site Classifications</u>

Independent variables which remain to be explored in conjunction with D10/D50 are those site variables which are confounded with surficial soil and each other in the Ralston Valley data. Since E4 has previously been found to vary significantly with site classification, it would be useful to do multivariate analysis with both site classification and D10/D50. Our approach will be to look for the effects of gradation measures <u>within</u> site classification.

As explained in an earlier section, confounding of site variables in the Ralston Valley data led to classification of sites as Type I sites (on or near the valley floor, with surficial soil type 5Y), Type II sites (on higher, more sloping ground with surficial soil type 5I), and Type III sites (same as Type I, but with surficial soil type U). It was shown that E4 varied significantly among the site types, leading to the observation that site classification might provide one basis for forecasting E4.

A first question we might ask is whether any or all of D10, D50, D10/D50, LCR, or CRD100 might vary significantly by site classification. Means, variances, and standard deviations are shown in Table 16. If each measure is viewed individually, variances differ significantly from Type I sites to Type II sites for D10, D50, D10/D50, and CRD100. Mean D10/D50 is different between Type I and Type II sites at the 5% significance level (Aspin-Welch test).

TABLE 16. Means, Variances, and Standard Deviations for Gradation Measures by Site Type.

		Type I Sites n=34	Type II Sites n=13	Type III Site n=4
D10	mean	0.0728	0.0434	0.0437
	variance	0.0195	0.0039	0.0020
	std. dev.	0.1395	0.0625	0.0447
D50	mean	1.210	1.199	0.458
	variance	3.040	0.976	0.052
	std. dev.	1.743	0.988	0.228
D10/D50	mean	0.06245	0.0334	0.118
	variance	0.00506	0.0004	0.016
	std. dev.	.0712	.0199	0.127
LCR	mean	5.506	5.760	4.205
	variance	1.467	0.836	0.316
	std. dev.	1.211	0.914	0.558
CRD100	mean	28.110	19.053	5.229
	variance	1208.1	97.273	15.262
	std. dev.	34.76	9.863	3.907

Sample correlation coefficients among gradation data at Type I sites are shown in Table 17. Here it may be seen that gradation measures in general and D10/D50 in particular have apparently a weaker relationship with E4 than they did with sites from the valley as a whole. With the reduced sample size, we need higher correlation values to catch our attention. Things look somewhat more promising at Type II sites, as reflected by the correlation values in Table 18.

The distinction in site types is amplified when we look at the data using linear and nonlinear regression analysis. Various functional forms which we previously explored for the valley as a whole were applied to data from Type I sites, and to data from Type II sites. Statistical results are summarized in Table 19, where we see that nothing works very well at all at Type I sites. At Type II sites, however, the nonlinear relationship between E4 and D10/D50 becomes again apparent in this subset of data, and in this case, a simple reciprocal function works very well. Here, the function is

$$E4 = 4.2 + 0.0088(D10/D50)^{-1} \quad .$$

We will discuss these and previous results in the next section.

TABLE 17. Sample Correlation Coefficients Among Gradation Measures at Type I Sites, n = 34.

	D10	D50	D10/D50	CRD100	LCR	E4
D10	1	0.43	0.55	0.54	0.12	-0.01
D50		1	-0.02	0.75	0.20	0.13
D10/D50			1	0.03	-0.24	-0.28
CRD100				1	0.65	0.06
LCR					1	0.07

TABLE 18. Sample Correlation Coefficients Among Gradation Measures at Type II Sites, n = 13

	D10	D50	D10/D50	CRD100	LCR	E4
D10	1	0.83	0.64	0.58	-0.44	-0.27
D50		1	0.19	0.64	-0.54	0.07
D10/D50			1	0.24	-0.18	-0.42
CRD100				1	0.15	0.04
LCR					1	-0.07

TABLE 19. Statistical Results for Linear and Nonlinear Regression Analysis at Type I and Type II Sites.

Function, where y = Mean E4, x = D10/D50	TYPE I SITES F(1,32)	Signif Level	Coef Determ	Std Error	TYPE II SITES F(1,11)	Signif Level	Coef Determ	Std Error
Linear: $y = a + bx$	2.693	NS	0.078	1.579	2.311	NS	0.175	0.805
Product: $y = ax^b$	2.192	NS	0.064	0.415*	5.029	5%	0.314	0.150*
Quadratic: $y = (a + bx)^2$	2.878	10%	0.082	0.393**	2.210	NS	0.167	0.182**
Exponential: $y = \exp(a + bx)$	3.068	10%	0.087	0.410*	2.078	NS	0.159	0.166*
Reciprocal: $y = a + bx^{-1}$	1.570	NS	0.045	1.605	11.73	1%	0.516	0.617

* These values are comparable to each other only.

** These values are comparable to each other only.

Conclusions and Discussion of Results

Among gradation measures considered, those locating the gradation curve (D10, D50, and CRD100) appear to have little connection with E4 as a single predictor. Among measures reflecting dispersion of particle size (CR, D50-D10, D10/D50), the ratio D10/D50 was found to relate to mean E4 in a statistically significant manner, although variance reduction was not large.

The performance of D10/D50 as a forecaster of E4 was improved by including D10 as a locating measure, in accordance with

$$\text{Mean E4} = \exp(1.1415 - 3.286(\text{D10}/\text{D50}) + 0.975\text{D10}) \quad .$$

Inclusion of other measures (including seismic) did not appreciably improve on this.

If we look within site classifications, the usefulness of D10/D50 decreases among Type I sites but improves at Type II sites, permitting good forecasting performance with a simple reciprocal relationship

$$\text{Mean IIE4} = 4.2 + 0.0088(\text{IID10}/\text{IID50})^{-1} \quad .$$

From all this, it appears that at least this rough dispersion measure is useful in forecasting mean E4. In this study only D10 and D50 were used from the bag-sample gradation curves, and it is tempting to consider how dispersion measures based on additional information from the sample gradation curves might perform.

Perhaps a word about the interpretation of these results is appropriate here. It has been said of exploratory data analysis that if you look long enough and hard enough, you will always find something. Hopefully, we have been careful not to go overboard in that direction. This data <u>does</u> appear to show a connection between a measure of soil particle size dispersion, D10/D50, and near-surface compressibility in terms of mean E4. It also seems clear from the data that the strength of this relationship is affected by whether the site is classified as Type I, or as Type II.

If we are asked to provide a description of this relationship, the functional forms presented in this report provide models which best represent <u>this</u> set of data. Variances are large enough here that if we had a different set of data, other functional forms might fit best.

Statistically, the use of hypothesis testing and significance testing tools in looking at this data require ever careful interpretation of what is really meant by "significant", "significantly different", and so on. This is because although many statistical tests have been reported, they all relate to essentially one set of underlying data. Thus the various test results are not independent of each other. We may be right about the significance level for one test, but we are not for the significance levels in a set of tests.

A continuing problem in this data analysis is the relatively high standard deviation of E4 at Type I sites, which are at the floor of the valley. In our initial work on site classification we found the boring to boring variation of E4 to be significantly different between the two groups of sites, with standard deviation 1.62 at Type I sites, and standard deviation 0.72 at Type II sites at higher elevations. One might have expected more uniformity in the floor of the valley; further, the E4 values are greater at Type II sites. The work reported in this section has shown that by using D10/D50 we can account for enough variance at Type II sites to reduce the standard deviation to the order of 0.62, but at Type I sites, the standard deviation remained at the order of 1.60. Also, the gradation measures all show greater variance among Type I sites than among Type II sites.

In the next section we shall look at relationships between porosity and compressibility in undisturbed core samples from Ralston Valley.

SECTION 6

POROSITY

Besides stress-strain curves and gradation, widely used dimensions for soils include water content, wet density, dry density, and porosity. All of these measures are somewhat related; in the analysis reported here emphasis was placed on porosity as a measure of interest in its own right as well as a potential predictor of near-surface compressibility.

Porosity Statistics

Porosity data from the 51 Ralston Valley borings appears to have a symmetric distribution. This is shown by the stemleaf diagram of the empirical c.d.f. in Figure 8.

Table 20 shows means, variances, and standard deviations for porosity according to site classification. Statistical tests were unable to find significant differences in the variance of porosity among site types, although numerically, there is greater variance among borings at Type I sites. In terms of mean porosity, Type I and Type III sites appear to be the same, but mean porosity at Type I and Type II sites is significantly different at the 5% level. Thus we conclude that porosity does differ according to site classification.

STEMLEAF PRSTY

```
26|1
28|03
30|8GIJ
32|3445ADEEH
34|01236679BCDFH
36|23BBHIJ
38|EHIIIJ
40|014EEI
42|8E
44|8
```

FIGURE 8. Stemleaf Plot Showing Empirical C.D.F. for Porosity at Ralston Valley Sites

TABLE 20. Means, Variances, and Standard Deviations for Porosity at Ralston Valley Sites.

	n	Mean	Variance	Std. Dev.
All Sites	51	0.359	0.00166	0.0407
Type I Sites	34	0.353	0.00190	0.0436
Type II Sites	13	0.380	0.00087	0.0295
Type III Sites	4	0.340	0.00051	0.0227

Relationships Between Porosity and Compressibility Measures

Sample correlation coefficients between porosity and various compressibility measures are shown in Table 21 both for all sites and according to site classification. (As in earlier studies as reported, we have omitted the Type III site from correlation and regression analysis because of only four observations.) The correlation values for all sites in general and for Type I sites in particular are all large enough to be interesting, and if we assume normality, are all statistically significant at 5% or better.

An unanticipated result here is the increase in

TABLE 21. Sample Correlations Coefficients for Porosity and Compressibility Measures in Ralston Valley.

	n	E2	E4	E6	E4-E2	E6-E4
All Sites	51	0.38	0.48	0.54	0.60	0.68
Type I Sites	34	0.38	0.48	0.54	0.61	0.70
Type II Sites	13	-0.13	-0.05	0.05	0.25	0.46

correlation as stress increases, from 2 to 6 MPa, with further increases as we go to incremental changes E2-0, E4-E2, E6-E4.

In attempting to relate various compressibility measures to porosity it was found that linear relationships generally outperformed nonlinear ones. A summary of statistical results from linear regression analysis is given in Table 22 with scatter diagrams shown in the Appendix. These results show that at Type I sites, consideration of porosity not only significantly improves estimation of mean compressibility measures, but also reduces variance somewhat. No significant relationships were found between near-surface compressibility and porosity at Type II sites.

TABLE 22. Statistical Results of Regression Analysis Between Compressibility Measures and Porosity.

$y = a + bx$

P = Porosity

	y	x	a	b	F	d.f.	Signif. Level	Coeff. Determ	Std. Error
All Sites:	E2	P	-1.02	10.16	8.24	1,49	1%	0.144	1.02
	E4	P	-2.58	18.06	14.49	1,49	Negl	0.228	1.37
	E6	P	-3.87	24.38	19.83	1,49	Negl	0.288	1.58
	E4-E2	P	-1.56	7.90	28.09	1,49	Negl	0.364	0.43
	E6-E4	P	-1.28	6.32	42.83	1,49	Negl	0.466	0.28
Type I Sites:	IE2	IP	-0.86	9.76	5.34	1,32	5%	0.143	1.06
	IE4	IP	-2.48	17.87	9.62	1,32	0.5%	0.231	1.44
	IE6	IP	-3.81	24.37	13.32	1,32	0.1%	0.294	1.67
	IE4-IE2	IP	-1.62	8.11	18.90	1,32	Negl	0.371	0.47
	IE6-IE4	IP	-1.33	6.50	30.19	1,32	Negl	0.485	0.26

Conclusions Regarding Porosity and Compressibility

In general, porosity appears to be related to near-surface compressibility measures, and the relationship may be reasonably represented as linear with positive slope. This relationship appears primarily at Type I sites which are those on the floor of the valley with surficial soil type 5Y. It was also observed that the greater the stress, the more the resulting strain relates to the porosity of the specimen.

Porosity produced a stronger relationship to near-surface compressibility than any factor considered in this study except site classification.

The next and final section of this report provides and overview of this analysis of data from Ralston Valley.

SECTION 7

CONCLUSIONS REGARDING PREDICTION OF NEAR-SURFACE COMPRESSIBILITY

The work reported here represents a first look at the geotechnical data base from Ralston Valley, Nevada, using modern statistical and data-based modeling techniques. The objective has been that of seeking relationships permitting prediction of subsurface soil properties for MX system design, so as to reduce the costs and time required for extensive boring, core sampling, and laboratory analysis.

A capsule summary of our findings with data from ten-foot depths at fifty-one borings in Ralston Valley might be given by the following statements:

1. The strongest predictor of near-surface compressibility that was found is a composite of site characteristics obtainable from maps, together with surficial soil type. (Sites on the valley floor with one soil type were found to have significantly different stress-strain relationships than sites above the valley floor with a different surficial soil type.)

2. Data that was examined from seismic surveys proved to be unrelated to near-surface compressibility.

3. When data from bag samples from ten-foot depths was examined, it was found that a dispersion measure from the gradation curve was strongly related to compressibility at sites above the valley floor. The variance, rather than the mean of particle size, was related to compressibility.

4. Porosity was found to be strongly related to near-surface compressibility at sites on the valley floor.

5. Pervasive throughout the analysis was the dependence of results on site location (with surficial soil type), and large residual variances in compressibility measures.

In terms of potential payoff in reducing costs for MX siting, the results of these statistical analyses appear promising, particularly since the best predictors found were those which simply used data taken from maps. This first look at the extensive Ralston Valley data base has identified factors which are promising as predictors of near surface compressibility, giving direction and focus to subsequent, more detailed work with this data.

Perhaps the most important general result of this study is its demonstration of the statistical modeling approach as a viable and inexpensive means of acquiring necessary inputs for the design of strategic structures.

REFERENCES

1. Vanmarke, Erik H. Probabilistic Soil Sampling Program For MX-Related Site Characterization. U. S. Army Engineer Waterways Experiment Station Misc. Paper SL 79-26, December, 1979.

2. Refraction Survey, Seismic P-Wave Velocities, Site REU, Ralston Valley, Nevada. Report prepared by Ertec Western, Inc., for U.S. Army Engineer Waterways Experiment Station, October, 1981.

3. Refraction Survey Seismic P-Wave Velocities, Ralston Valley, Nevada. Report prepared by FUGRO, Inc., for U.S. Army Engineer Waterways Experiment Station, April, 1980.

4. Refraction Surveys at Selected Locations in the Proposed MX Siting Area. Report prepared by FUGRO, Inc., for U.S. Army Engineer Waterways Experiment Station, March, 1981.

5. Phillips, B.R., MC Task V-1: Results from Laboratory Tests on the Subsurface Materials Obtained from the Ralston Valley and Dry Lake Valley Geotechnical Study Sites. Structures Laboratory, U.S. Army Engineer Waterways Experiment Station, December, 1980.

6. Phillips, B.R., Results from the Subsurface Exploration Programs at the Ralston Valley and Dry Lake Valley Geotechnical Study Sites. Structures Laboratory, U.S. Army Engineer Waterways Experiment Station, October, 1981.

7. Phillips, B.R., Ralston Valley Soil Compressibility Study: Interpreted Boring Logs. Structures Laboratory, U.S. Army Engineer Waterways Experiment Station, April, 1981.

8. Creighton, D.C. Ralston Valley Soil Compressibility Study: Data Base Generation and User's Guide for Sarforms. Structures Laboratory, U.S. Army Engineer Waterways Experiment Station, September, 1981.

9. Box, G., W.G. Hunter, and J.S. Hunter. Statistics for Experimenters. Wiley, 1978.

10. Kmenta, Jan. Elements of Econometrics, MacMillan, 1971.

APPENDIX

TABLE 23. List of Borings from which Data was used.

RA5Y1	RC5I1	RDU1
RA5Y2	RC5I2	RDU2
RA5Y3	RC5I3	RDU3
RA5Y4	RC5I4	RDU4
RB5Y1	RD5I1	RA4U1
RB5Y2	RD5I2	RA4U2
RB5Y3	RD5I3	RA4U3
RB5Y4	RD5I4	RA4U4
RC5Y2	RAU1	RB4U1
RC5Y3	RAU2	RB4U2
RC5Y4	RAU3	RB4U4
RD5Y1	RAU4	RC4U1
RD5Y2	RBU1	RC4U2
RD5Y3	RBU2	RC4U3
RD5Y4	RBU3	RC4U4
RA5I1	RCU1	RD4U1
RA5I2	RCU2	RD4U2
RA5I4	RCU3	RD4U3
RB5I2	RCU4	RD4U4
RB5I3		

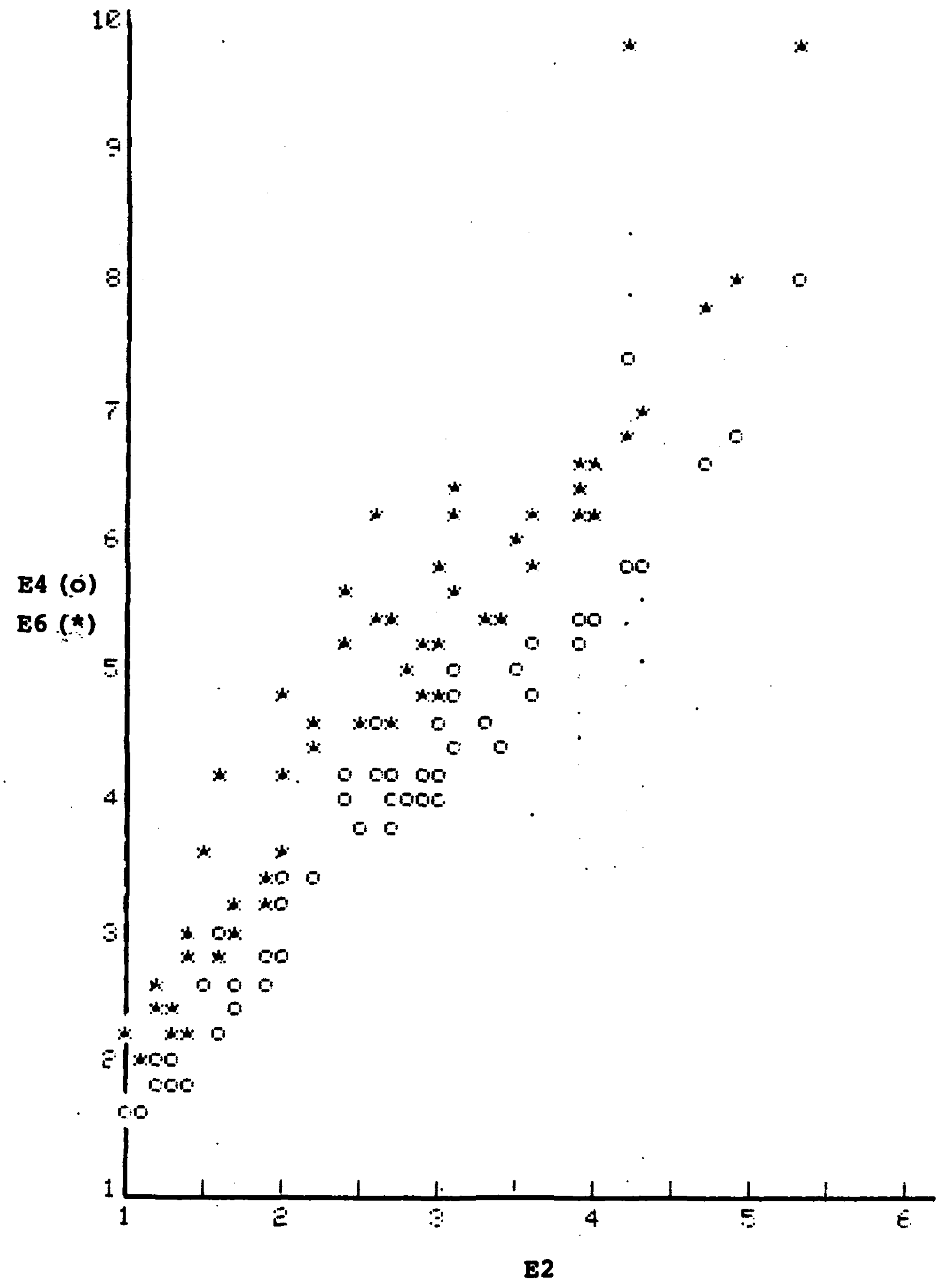

FIGURE 9. Plot Showing E4 and E6 vs E2.

TABLE 24. Compressibility Data for Type I Sites

E2	E4	E6	E4-E2	E6-E4	
2.57	4.58	6.22	2.01	1.64	0.377
2.89	3.99	4.8	1.1	0.81	0.337
4.67	6.54	7.77	1.87	1.23	0.353
3.48	4.92	5.95	1.44	1.03	0.325
1.38	2.26	2.97	0.88	0.71	0.346
4.24	5.74	6.75	1.5	1.01	0.308
2.98	4.55	5.86	1.57	1.31	0.428
1.58	2.29	2.89	0.71	0.6	0.379
1.37	2.15	2.82	0.78	0.67	0.346
2.84	3.95	4.9	1.11	0.95	0.394
5.3	8.04	9.78	2.74	1.74	0.448
2.68	4.09	5.37	1.41	1.28	0.397
4.3	5.87	6.95	1.57	1.08	0.343
1.86	2.65	3.18	0.79	0.53	0.261
2.03	3.21	4.21	1.18	1	0.333
1.72	2.53	3.21	0.81	0.68	0.378
1.64	3.01	4.18	1.37	1.17	0.355
1.18	1.84	2.4	0.66	0.56	0.283
4.01	5.46	6.56	1.45	1.1	0.398
3.63	4.84	5.75	1.21	0.91	0.324
3.08	4.49	5.53	1.41	1.04	0.347
2.97	4.28	5.2	1.31	0.92	0.33
2	2.84	3.43	0.84	0.59	0.28
1.93	2.8	3.44	0.87	0.64	0.324
2.54	3.72	4.69	1.18	0.97	0.371
2.97	4.01	4.75	1.04	0.74	0.334
1.99	3.44	4.72	1.45	1.28	0.341
4.23	7.41	9.75	3.18	2.34	0.434
1.86	2.69	3.49	0.83	0.8	0.352
1.53	2.61	3.67	1.08	1.06	0.398
1.26	1.82	2.29	0.56	0.47	0.319
1	1.6	2.1	0.6	0.5	0.34
1.42	1.79	2.12	0.37	0.33	0.316
2.74	4.17	5.42	1.43	1.25	0.414

TABLE 25.Site Characteristics for Type I Sites

ELEV	SLOPE	EAC	DFM	DCV	DEP
1689	2.27	18.288	5.21	5.31	22.67
1689	2.27	18.288	5.21	5.31	22.67
1689	2.27	18.288	5.21	5.31	22.67
1689	2.27	18.288	5.21	5.31	22.67
1670	1.34	9.144	3.11	4.51	16.46
1670	1.34	9.144	3.11	4.51	16.46
1670	1.34	9.144	3.11	4.51	16.46
1597	1.58	12.192	1.46	8.21	1.22
1597	1.58	12.192	1.46	8.21	1.22
1597	1.58	12.192	1.46	8.21	1.22
1597	1.58	12.192	1.46	8.21	1.22
1707	1.07	6.096	2.6	0	29.19
1707	1.07	6.096	2.6	0	29.19
1707	1.07	6.096	2.6	0	29.19
1707	1.07	6.096	2.6	0	29.19
1585	0.43	0	3.75	5.95	1.22
1585	0.43	0	3.75	5.95	1.22
1585	0.43	0	3.75	5.95	1.22
1585	0.43	0	3.75	5.95	1.22
1667	0.66	0	6.86	2.57	21.61
1667	0.66	0	6.86	2.57	21.61
1667	0.66	0	6.86	2.57	21.61
1667	0.66	0	6.86	2.57	21.61
1625	0.5	0	9.12	3.14	13.73
1625	0.5	0	9.12	3.14	13.73
1625	0.5	0	9.12	3.14	13.73
1600	0.19	0	10.19	0.31	5.21
1600	0.19	0	10.19	0.31	5.21
1600	0.19	0	10.19	0.31	5.21
1600	0.19	0	10.19	0.31	5.21
1589	0.08	3.048	4.89	5	5.95
1589	0.08	3.048	4.89	5	5.95
1589	0.08	3.048	4.89	5	5.95
1589	0.08	3.048	4.89	5	5.95

TABLE 26. Compressibility Data for Type II Sites

E2	E4	E6	E4-E2	E6-E4
2.95	4.24	5.2	1.29	0.96
2.38	4.05	5.26	1.67	1.21
3.87	5.47	6.63	1.6	1.16
2.43	4.11	5.61	1.68	1.5
3.09	4.96	6.33	1.87	1.37
3.89	5.32	6.3	1.43	0.98
2.92	4.28	5.27	1.36	0.99
3.93	5.2	6.12	1.27	0.92
2.87	4.23	5.27	1.36	1.04
2.55	4.16	5.38	1.61	1.22
2.2	3.43	4.58	1.23	1.15
3.09	4.85	6.22	1.76	1.37
4.85	6.71	7.98	1.86	1.27

TABLE 27. Site Characteristics for Type II Sites

ELEV	SLOPE	EAC	DFM	DCV	DEP
1774	2.53	42.672	2.28	2.04	32.57
1774	2.53	42.672	2.28	2.04	32.57
1774	2.53	42.672	2.28	2.04	32.57
1731	3.03	36.576	1.78	4.81	25.2
1731	3.03	36.576	1.78	4.81	25.2
1731	2.6	73.152	1.22	6.6	18.14
1731	2.6	73.152	1.22	6.6	18.14
1731	2.6	73.152	1.22	6.6	18.14
1731	2.6	73.152	1.22	6.6	18.14
1670	3.03	57.912	0.93	8.69	8
1670	3.03	57.912	0.93	8.69	8
1670	3.03	57.912	0.93	8.69	8
1670	3.03	57.912	0.93	8.69	8

TABLE 28. Compressibility Data for Type III Sites

E2	E4	E6	E4-E2	E6-E4
1.06	1.6	2.07	0.54	0.47
1.73	2.4	2.93	0.67	0.53
1.29	1.95	2.49	0.66	0.54
1.21	1.93	2.51	0.72	0.58

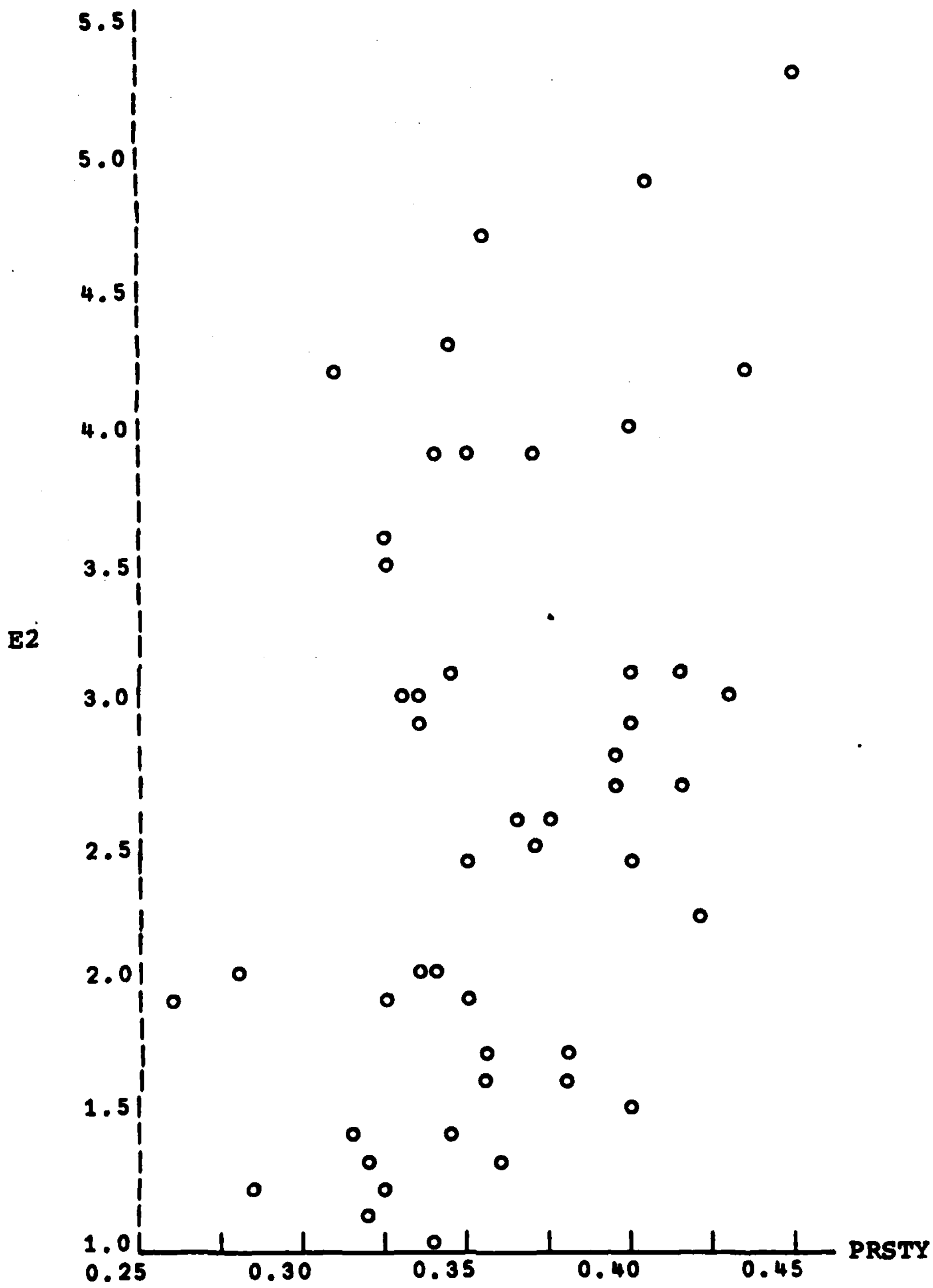

FIGURE 10. Scatter Plot: Porosity and E2

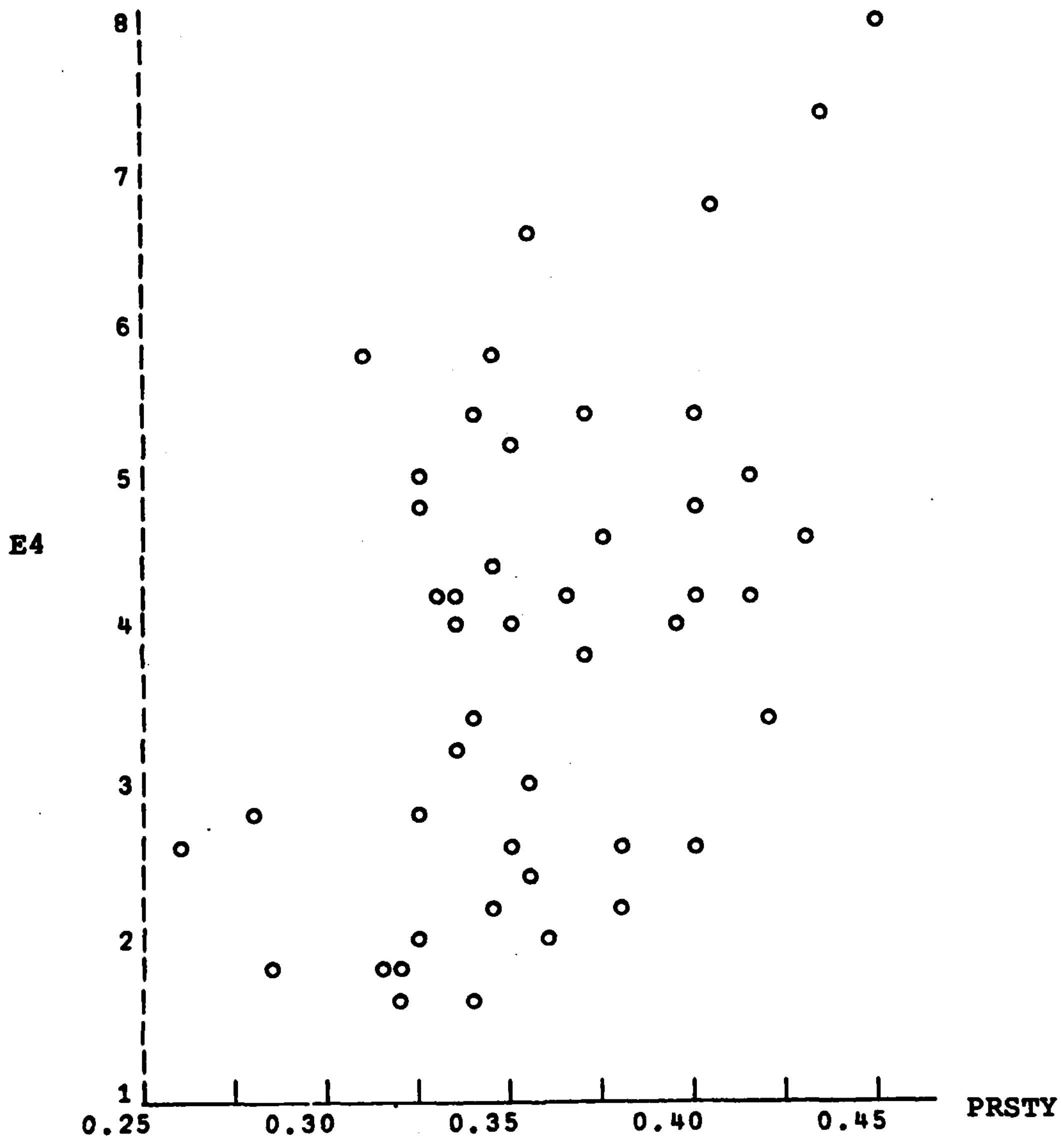

FIGURE 11. Scatter Plot: Porosity and E4

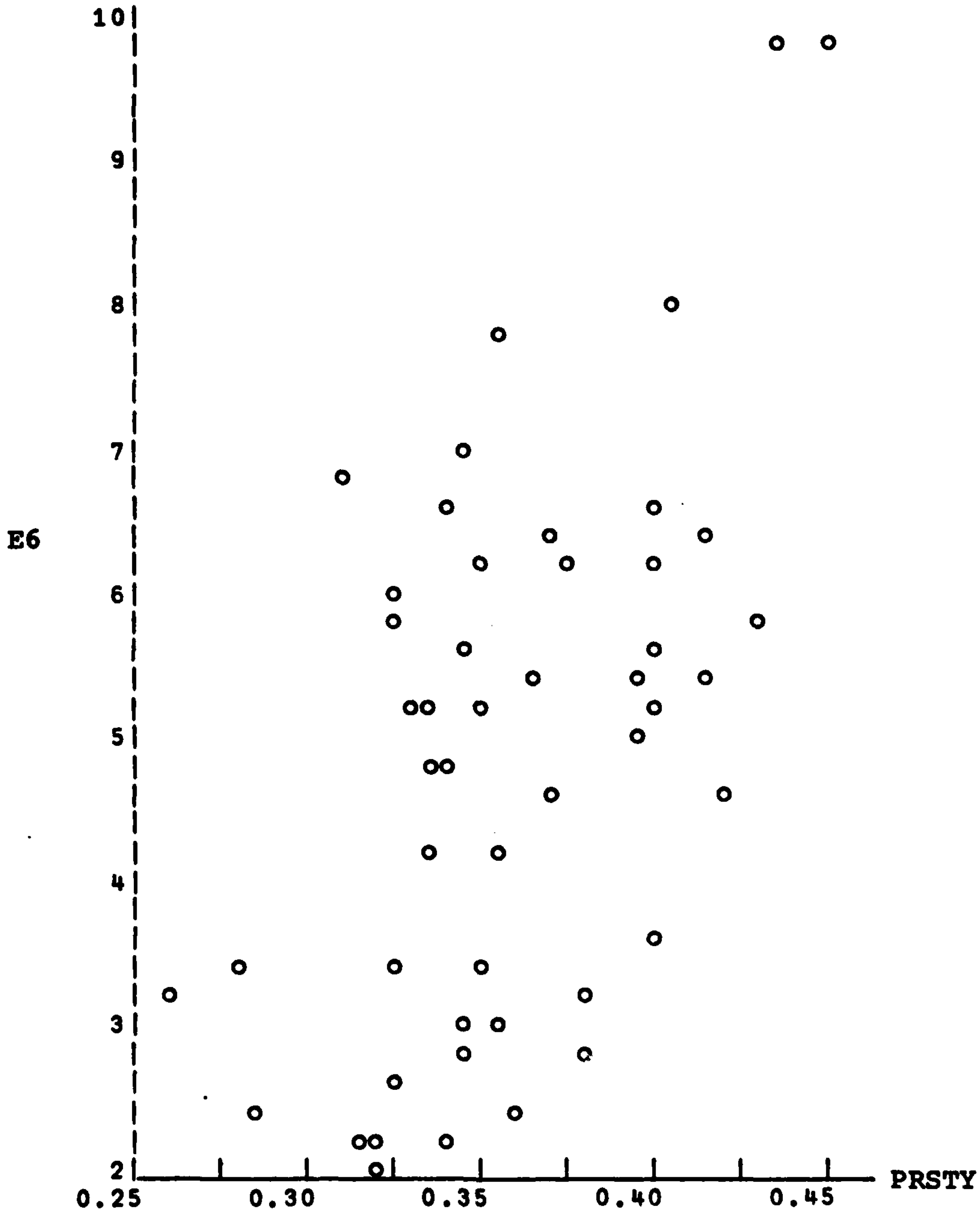

FIGURE 12. Scatter Plot: Porosity and E6

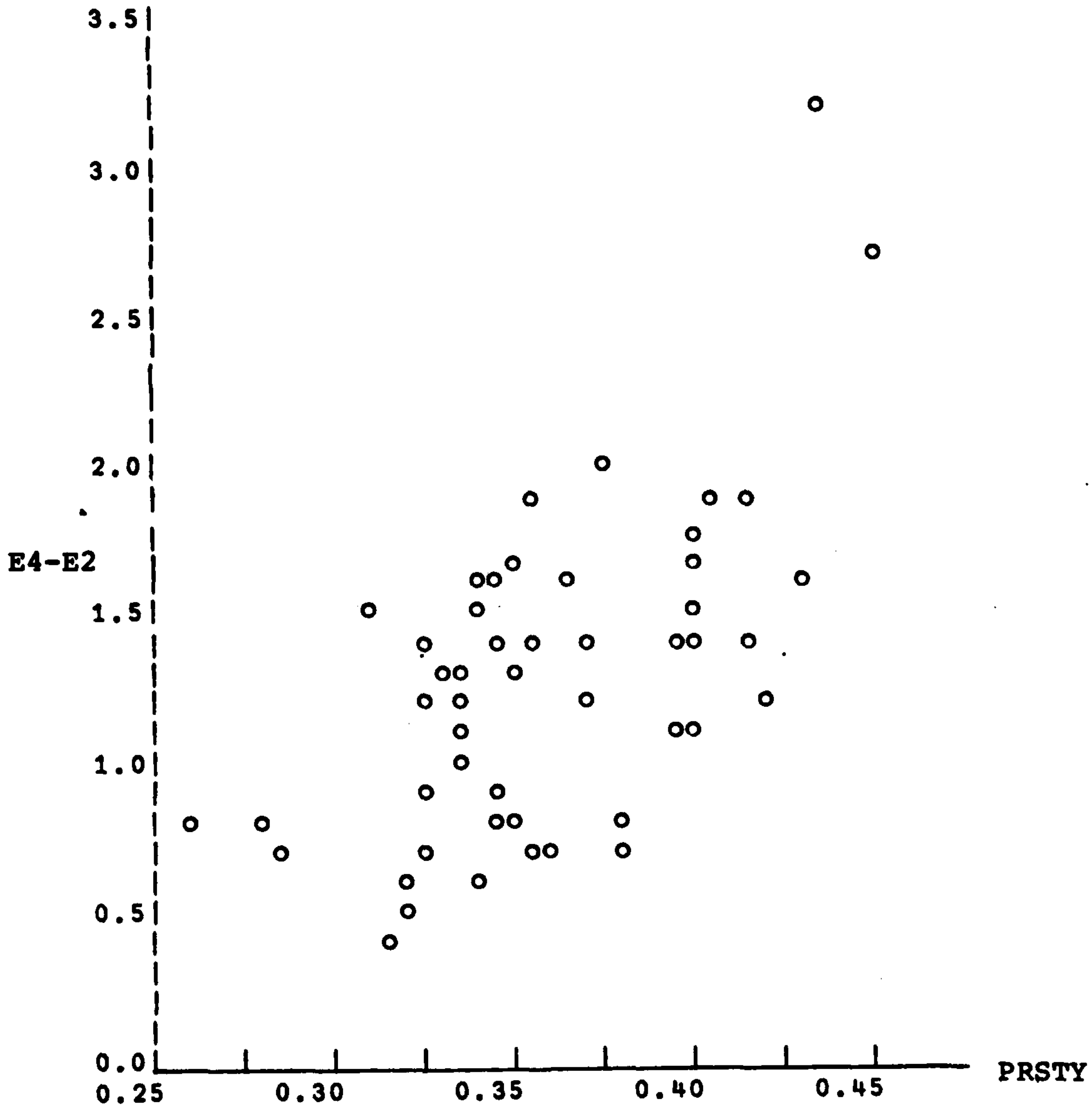

FIGURE 13. Scatter Plot: Porosity and E4-E2

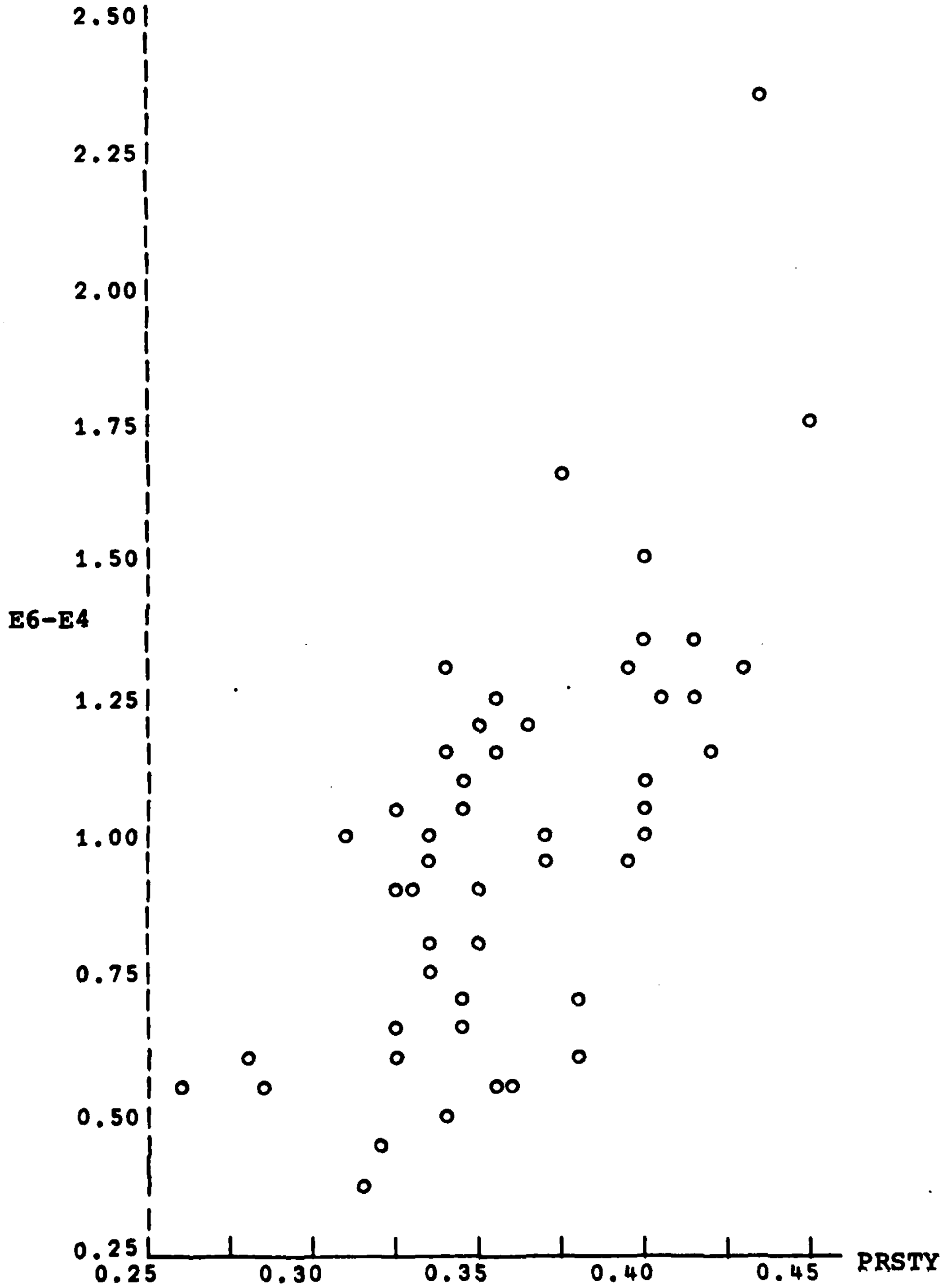

FIGURE 14. Scatter Plot: Porosity and E6-E4

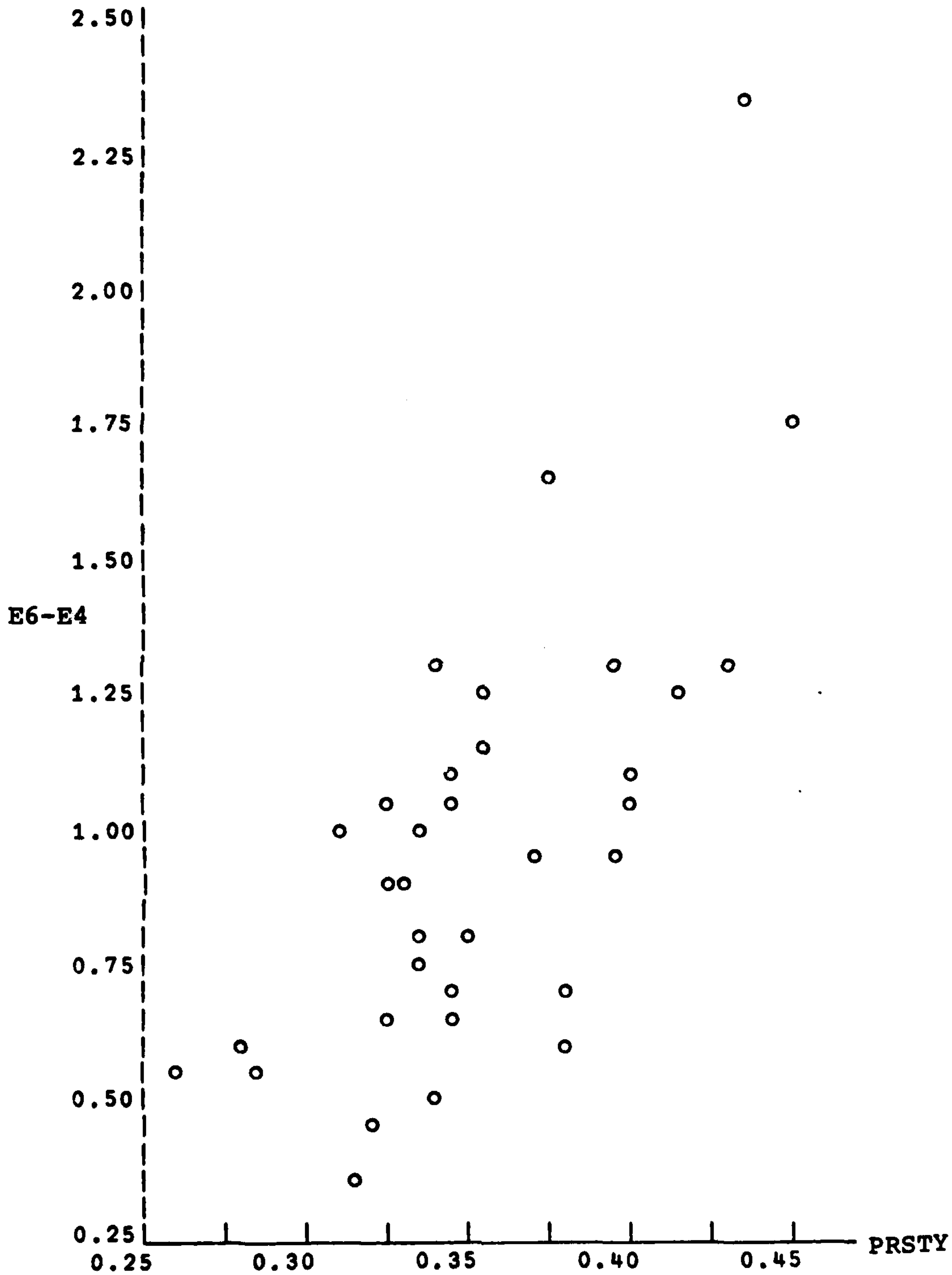

FIGURE 15. Scatter Plot: Porosity and E6-E4 at Type I Sites.

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